WAHL

Applications of
Compressed Air
for Motive Power

Mechanical Engineering

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Applications of Compressed Air for Motive Power

..BY..

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THESIS

FOR THE DEGREE OF BACHELOR OF SCIENCE IN

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

Henry Wahl

ENTITLED Compressed Air

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE

OF Bachelor of Science in Mechanical Engineering.

L. P. Breckenridge

HEAD OF DEPARTMENT OF Mechanical Engineering.

Historical Review of the Uses of Compressed Air.

The first authentic patent for compressed air machinery was taken out in England in 1726 by Rowe. From that time up to the beginning of the nineteenth century there were many attempts to pump water by means of slightly compressed air.

In 1799 Medhurst took out a British patent to compress air for motive power by means of a wind-mill, and in 1828 Bompos in a provisional British patent proposed to propel locomotives by compressed air. In the same year Colladon proposed to employ compressed air in the Thames tunnel.

However, the first decided advance in the science of compressed air and its applications was made by William Mann. In his patent he states that by application of compressed air, power and motion can be communicated to fixed machinery, carriages, locomotives and ships. In the description of his method of compressing air, he says: " The condensing pumps used in compressing the air I make of different capacities, according to the density of the fluid to be compressed, those used to compress the higher densities being proportionally smaller than those previously used to compress it at the first or lower densities. It is evident from this extract that Mann discovered the advantage of compound compression.

In 1836 James Surrey in a British patent suggests portable vessels filled with compressed air for the use of railways; he also suggests a central compression plant with a system of piping between stations.

In 1844 Arthur Parsey patented a regulating device between the

receiver and cylinder.

In 1847 Von Rathen in an English patent describes the processes of wet cooling and jacket cooling; he also describes a refrigerator for cooling the air after compression and also a reheater.

In 1852 Colladon applied for an Italian patent for the use of compressed air as a power for driving the rock drills in tunnel construction.

January 15th. 1854 Arthur Parsey patented in England the double acting air pump with hollow piston rod, through which air is admitted. The valve may be as large as the cylinder. The rod passes through the valve and has a spiral spring to keep the valve seated.

The above summary is intended to point out in a slight degree the most important steps in the development of the compressed air machinery of the present day.

Compressed Air as a Motive Power for Vehicles or Trucks.

The "Compressed Air" for March 1900 gives illustrations and descriptions of compressed air propelled vehicles showing their development in the line of the auto-truck. The New York Auto-Truck Co. has been carrying on a line of experiments to demonstrate the feasibility of compressed air vehicles for street haulage.

The first carriage of this type was built in 1895 and 1896 to establish the general principles, the milage, regulation and control by this power. The power was applied by a Hoadley-Knight motor. It was found that on one charge it would run 14 miles and ascend a grade of 20 per cent at 8 miles an hour. Air was reheated by a small coal fire.

The second vehicle was a factory truck for handling heavy weights around the factory yard at Worchester, Mass.; it was capable of carrying 10 tons. This vehicle had no provision for preheating, as it was not required to run long distances, and it could be recharged at any moment.

With this development to demonstrate the power and feasibility of compressed air a tractor was built, which was a sort of compressed air locomotive. The power was controlled by the feet and the steering was done by the hands. Controlling treadles extended out from the standard in front of the drivers seat, convenient as a foot rest.

By pushing one foot down the vehicle was caused to go forward, and by pushing the other foot down it was caused to go backwards, while putting both feet down in a medium position brought the vehicle

to a standstill. This tractor is said to have developed a hundred horse-power and to have hauled 40 tons on railroad cars. Hot water under 600 pounds steam pressure was used for reheating.

The tractor may be seen hauling railroad cars and also pulling coal wagons on the streets of Worchester, Mass. Other tractors were built on similar lines, and were used in Providence, R. I. at the works of the International Power Co., for factory work. In connection with a low gear truck, the forward wheels of the gear being dispensed with and its forward end being hung by a link under the rear axle of the tractor, thus making a "Lorry" of the tractor. This was followed by the auto-truck which was adapted to carry a load on its back and represents the most powerful automobile which has yet been produced. It is capable of carrying a load of 10 tons up a grade of 10 per cent.

The view shown was taken in Providence, R. I. The truck was used for factory work, hauling large castings. It was afterwards taken to New York and used there for hauling lumber. The weight of the loads shown was 18000 lbs. This truck in the prototype of other trucks now being built by the International Power Co., and they differ in points, weights and material. The weight of the new truck is much less and the material of a character designed for permenancy.

"Compressed Air" of January 1900 contains a cut and description of an air driven wagon.

The engine used in the air wagon is of the usual two cylinder type and weighs 36 lbs. and has several special features in its construction. It is adapted for the use of steam or air, as required. With the use of air it has a storage capacity of six cu. ft. which

could be increased without material addition to the total weight of the wagon, which is with the present capacity 670 lbs.

With air as a power, appliance for reheating the air is used. The air is stored at a pressure of 2500 pounds per. square inch and reduced to an initial pressure of 150 pounds by an arrangement of reducing valves, which are under the control of the operator, and allows the working pressure to be regulated as required.

On a recent trial on bad road this wagon was operated with a consumption of 60 cubic feet of free air per. mile. The conditions of the road was much below the average, and the trial was not one which would give the most economical results in the use of the power, yet under these conditions, the storage has capacity to run the carriage twenty or thirty miles.

"Compressed Air" of December 1898 contains the following in regard to a compressed air truck.

The truck shown in cut is of one in daily use at the works of the American Wheelock Engine Co., Worchester, Mass., and is used for moving large castings and other bulky work from place to place.

This truck will handle ten tons and occupies a space of four by fifteen feet. It is claimed that it will run about half a day on one charge of air and will operate with a power cost not exceeding one cent a mile. The motor used is of the Hoadley-Knight type, that is to say, it is an iron-clad motor having all its working parts in a closed iron basin partly filled with oil so that no attention for lubrication is required.

A simple wedge movement enables its operator to reverse the motor or control the point of cut-off. This is done by the lower hand wheel shown in the cut. The upper wheel is for steering purposes, it being connected to a segmented gear, attached to a single steering wheel. The throttle is controlled by a lever which is opened by the operator pressing his knee against it and is closed by a spring. The motor drives both the rear wheels through a compensating bevel gear arrangement thus allowing it to turn in any direction. The truck when working under ordinary conditions, consumes about 75 cubic feet of air per mile. This involves a cost of less than one cent per mile for power.


N.Y. AUTO-TRUCK
Nº5
Horton Bros photo.


SIMPSON TOLAN
LUM ER 196
N.Y. AUTO-TRUCK
Nº 5

COMPRESSED AIR TRUCK.

THIS AUTOMOBILE IS OPERATED BY COMPRESSED AIR, AND BUILT BY THE AMERICAN VEHICLE CO., NEW YORK.

A TYPICAL MOTOR TRUCK. MOTIVE POWER, COMPRESSED AIR.

Compressed Air as a Motive Power for Locomotives.

The Railway Journal of June 1899, Vol. 2 page 14, contains the following about compressed air locomotives in practical operation at the mines of the Philadelphia and Reading Coal and Iron Co.,Ashland Coal and Iron Co., and the Jefferson Coal Co., also at the works of the Plymoth Cordage Co. The users of these locomotives report that they are doing excellent service.

It is claimed that these engines for the service intended are more reliable and more economical in installation and operation than other systems.

They are absolutely safe from fire amd handier in operation than a steam engine of the same size. The leading anthracite and bituminous colliers have adapted them after exhaustive examination. We are therefor forced to accept the claims made in their favor.

The compound system shown in the P. and R. C. and I. Co. engine number 44 is found to be more economical in the use of air as it gives a greater range of expansion in the cylinders than the ordinary single expansion system. This engine was the first one of its type put into service and has handled 45 empty coal cars weighing 2300 pounds each on a grade of 1.6 per. cent.

These air engine tanks usually carry a working pressure of 600 pounds per. square inch.

Specifications of some of these engines are given below:-

Four-coupled mining pneumatic locomotive for the Ashland Coal and Iron Co.-------Cylinders 14x9 with plain valve; air tanks, one 26.5 inches in diameter and 18 feet 5 inches long; one 26.5 inches in

diameter and 15 feet 9 inches long; one 15.75 inches in diamater and 13.feet 5.75 inches long, thickness of sheet 1/2 inch and 3/8 inch, thickness of head 5/8 inch, working pressure 100 pounds, storage pressure 600 pounds.

Driving wheels, outside diameter 28 inches, diameter of center 24 inches, journals 4x6 inches; wheel base, drivers 5 feet 3 inches, weight on drivers 20500 pounds, gauge 3 feet 7.5 inches.

Compound four-coupled mining pneumatic locomotive for the Philadelphia and Reading Coal and Iron Co.--------Cylinders, diameter, high pressure 5 inches,,low pressure 8 inches, stroke 12 inches, balanced piston valve. Air tanks; one 32 inches in diameter 16 feet long, one 32 inches in diameter 13 feet 6 inches long, one 14.5 inches in diameter 13 feet 4 inches long. Thickness of sheets 3/8 inches, thickness of head 9/16 inches, working pressure 200 pounds, storage pressure 600 pounds.

Limit of height of engine 5 feet 3 inches, limit of width 6 feet, limit of length 16 feet.

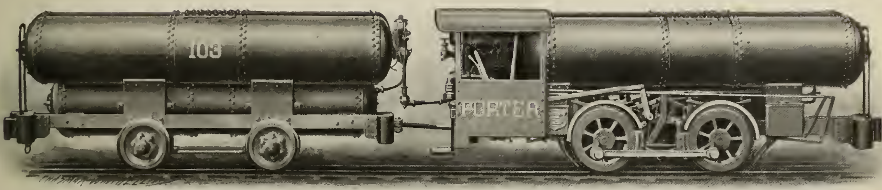
Driving wheels, outside diameter 24 inches, diameter at center 20 inches, journals 4x6 inches, wheel base driving and total 4 feet 6 inches, weight on drivers and total 22000 pounds, gauge 3 feet 8 in.

The McCormick Harvesting Co. of Chicago have six compressed air locomotives to take the place of about sixteen drays in doing their draying. The compressed air power being the safest as there was so much inflamable material and danger from fire. No tests have been made as to the amount of air required to run those locomotives but it is said that they will work continuously for about two hours on one charge using air at twenty-five hundred pounds pressure.

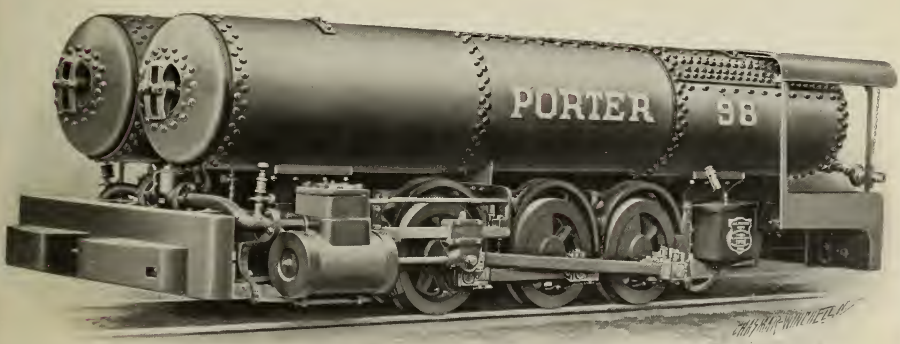
The following photographs of the Porter locomotives were furnished with the compliments of the manufacturers.


BREEZE.
1335

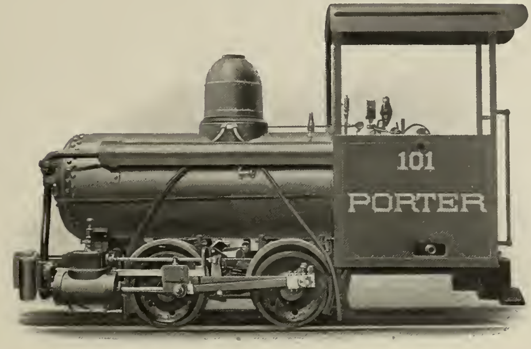
Compressed Air Mine Locomotive, Four Driving Wheels, with Four-Wheel Air Tender



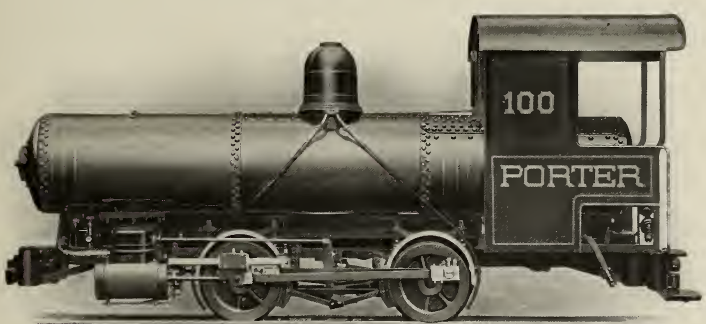
Compressed Air Mine Locomotive, Two Tanks, Six Driving Wheels



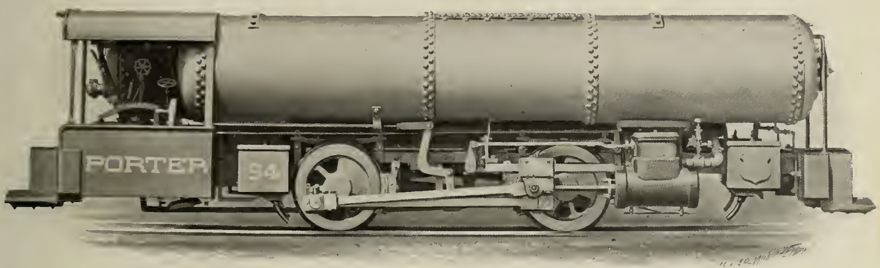
Compressed Air Industrial Locomotive, Single Tank, Four Driving Wheels



Compressed Air Industrial Locomotive, Two Tanks, Four Driving Wheels



Compressed Air Mine Locomotive, Two Tanks, Four Driving Wheels



Compressed Air Mine Locomotive, Single Tank, Four Driving Wheels

Cpmpressed Air as a Motive Power for Street Railways.

"The American Machinist" for May 6th. 1898 describes the Hardie system of compressed air locomotives for the Manhattan Elevated R. R. of New York.

The air at a pressure of 2000 pounds to the square inch is carried in 36 Mannesman tubes, each nine inches in diameter and fifteen feet six inches long. The total cubical contents is 246 cubic feet, which at above pressure is equivalent to 33702 cu. ft. of free air. The weight of the full charge of dry air will be over 2500 pounds.

The tubes are all so connected, the connections being in the forward end and easily accessible, as to form one continuous reservoir. The air first passes from the reservoir to a pressure-reducing valve which maintains a constant working pressure of 150 pounds, which pressure, within certain limits, may be varied under the control of the engineer.

The air, after its expansion to this working pressure, passes through a vertical tank of hot water in the cab. This water is heated by steam, at each recharging of the air reservoirs, tó about 350 degrees F. The air passes actually through the hot water and is thereby not only heated and expanded but takes up a volume of steam about equal to one half its own volume, the actual practical results of the expansion of the air and mixture of steam with it being to double the work done by the air.

From the heater the air goes as directly as possible to the engine cylinders. These are 13.5 inches in diameter and 20 inches stroke, being placed under the cab instead of in the usual place forward.

This arrangement is done to secure as short a run as possible from the heater to the cylinder.

As the cylinders on the steam locomotives on this line are only 12 inches diameter, the air locomotive will have more power, will start the trains quicker from the stations, and will be able to make better time.

Cassiers Magazine for June 96 contains the following on " Compressed Air for Street Railways", by Whitfield Price Pressinger.

Up to this time an impartial and fair demonstration had not been made of the use of compressed air in street car service. In this employment it can present no arbitrary claims for its adoption but must compete on an equal footing with established methods, the basis for this comparison being cost of installation and operation. When the inventer who undertakes to design and construct a compressed air street motor, is able to convince street railroad capitalists by an actual demonstration that his system can be installed and successfully operated at a reduced cost per. car run, then, and then only will compressed air be used in service. The history of the various compressed air motors which have been exploited from time to time is a checkered one, but the fact that compressed air yet lacks a thorough demonstration, is due either to incompetent efforts or to causes entirely foreign to and beyond the control of those interested.

The first to be tried, in America at least, was the Hardie motor, which was constructed at the Baldwin Locomotive Works at Philadel-

phia and tested in New York city about 1881.

Subsequently the Judson system, taking its power from a continuous compressed air conduit the entire length of the line, was tested and abandoned. Then the Atmospheric Propulsion Co. built an experiment car and progressed no farther. The rights of the Mekarski system, extensively used in France, are controlled in the United States and cars have been run here, but it has not flourished as in the land of its conception.

All these motors, with the exception of the Judson, were designed upon the storage system being provided with cylindrical receivers carried under the car body. These receivers were charged at a central station with compressed air to a high pressure and the air was supplied to the motor cylinder on the car, at the requisite working pressure, by means of pressure reducing valves. Provision was made for restoring the radiated heat energy to the air before it was used and air brakes were employed.

On down grades no air was consumed and in fact, the motor cylinders could be utilised as compressing pumps, to restore air under pressure to the receiver whenever the car was propelled by gravity. The entire mechanism was controlled by the motorman from his place on the front platform and required no higher grade of ability than in managing a cable or trolley car.

In this employment of compressed air power as in others, Continental Europe and particularly France, made the earliest demonstration of any magnitude. In the suburbs of Paris and at Nantes compressed air tramways have been in operation for several years.

A report relative to the tramway near Paris states that the many advantages of this system have been fully established by over two years experience and claims the following. The motor does not emit smoke or hot gases and is almost noiseless. Any desired rate of speed can be attained and may be varied at will to suit conditions. A special track or overhead appliance is unnessary. Being very light it can be easily handled on steep grades. Simple in form it does not frighten horses; the machinery on the front platform is almost invisible from the outside. One person only is required to manage the machinery and he need not necessarily be a skilled engineer.

The principle of the system is very simple; the storage reservoirs of the car are charged with compressed air at the supply station to a pressure of 45 pounds and reduced and used at 5 to 10 pounds, being at the same time heated to a high temperature and charged with moisture in a heating vessel.

Another method tried in Paris was the Popp-Conti system. The details of their invention vary from the other prominent methods in that a low air pressure is employed, the car reservoirs being recharged automatically at intervals along the line.

The Journal of the Franklin Institute for July, August and September of 1899 contains the following in regard to pneumatic transportation and cuts of cars operated under different systems. The systems are, the Hughes and Lancaster System, the Jarvis System and the Mekarski System at Toledo Ohio.

The cost of operating air cars based on seven months operation

begining August 3rd. 1896. The length of track is 10854 feet or 4.11 miles on which two air cars were substituted for cable cars each making nineteen round trips or 79.09 miles per car. The total daily distance traversed being 157.32 miles. Each car runs from 12.5 to 16.67 miles on a single charge of air.

Actual average cost per car mile for entire period, seven months, 125.16 miles per. day.

Coal----------------------------------	$ .0563
Water---------------------------------	.0103
Oil and Waste-----------------------	.0013
Power Plant Labor-------------------	.1261
Conductor and Motorman-------------	.0608
Repairs, Car Equipment-------------	.0038
Total---------------------------------	$ .2586

Average present cost per car mile with one car service performed 78.09 miles per. day.

Coal----------------------------------	$ .0675
Water---------------------------------	.0113
Oil and Waste-----------------------	.0017
Power Plant Labor-------------------	.0833
Conductor and Motorman-------------	.0698
Repairs, Car Equipments-------------	.0038
Total---------------------------------	$ .2284

Average present cost per car mile with two car service 156.18 miles per. day.

Coal	$ .0433
Water	.0103
Oil and Waste	.0013
Power Plant Labor	.0833
Conductor and Motarman	.0608
Repairs, Car Equipment	.0028
Total	$ .2018

If the proportion of labor actually utilised in this service is considered, the expense would only amount to $ .1791 per. car mile at present.

Present number of employes six beside motorman and conductor.

The cost of operating the same line, 4.11 miles, with electric cars was $ .2991 having however only five employes.

The average consumption of free air per. car mile for the seven months service was 477.7 cubic feet.

In a severe snow storm the cars performed schedule time carrying twenty per cent. more passengers and using twenty-two per cent more power than the day previous. Comparing results with an electric road with thirty-three per. cent less service than the day previous the load on the power plant was eighty per cent greater.

The air storage reservoirs on these cars have a capacity of 51 cubic feet sufficient to run the car 18 to 20 miles continuously.

The reservoirs consist of seamless steel flasks capable of standing a pressure of double that used without reaching the elastic limit of the metal and there is no possibility of leakage. Between the flasks and the motor is placed a small tank containing 6 cubic feet

of water which is heated by passing steam through it while the air flasks are being charged. This tank is lagged with non-conducting material so as to prevent loss of heat. Numerous experiments have proved that the cars will run nearly twice the distance with air heated in this way as with cold air.

The air is exhausted so low as to cause no sound in exhausting.

The motor mechanism consists of two simple link-motion reciprocating engines having cylinders 7 inches in diameter and 14 inch stroke with valve cutting off at 1/10 to 1/6 and applying power by connecting and parallel rods direct to the crank pins of the drive wheel, which are 4 in number, 26 inches in diameter, running on a wheel base of 7.5 feet. Upon this four wheeled truck rests the entire weight of the car and mechanism evenly distributed upon eliptical springs.

The mechanical features of the motor are substantially the same as steam locomotive minus boiler and fire-box and needs no comment.

The car is simple in manipulation, perfectly noiseless, odorless, and free from all offensive features which place it at the top for a public conveyance.

In the report of the Metropolitan Street Railway Co. New York, for the year ending June 30th. 1900 the comparison of the relative cost of operating cable, electric and horse railroads is given. It is there stated that the total operating expenses for 9812031 horse-car miles averaged 18.98 cents per. car-mile; that 10610091 cable-car miles averaged 17.76 cents per. car-mile and that

24968196 electric-car miles averaged 13.16 cents per. car-mile. These figures were made to include all expenses as nearly as possible. The compressed air cars on the 28th. and 29th. street lines in New York have been running about two months, and in that time have run considerably less than 100000 miles. The maximum number of cars being twenty.

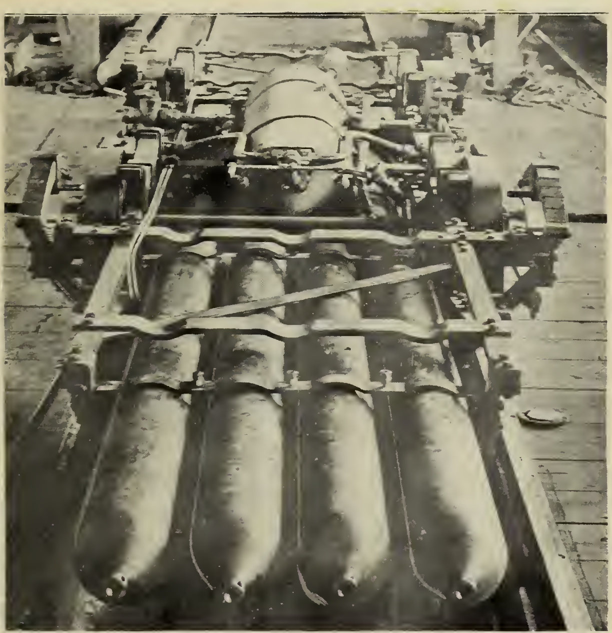
Careful estimate, made to conform as closely as possible to the scope of the report previously quoted, establishes 17.42 cents per. car-mile for the compressed air operation to date.

When it is considered that these twenty cars are being operated from a central plant, which has a capacity for probably 100 cars of the same individual power as that now used, the further estimate made by the Compressed Air Co. showing that this cost can probably be reduced to 13.57 cents is not unreasonable.

THE NEW HARDIE AIR-MOTOR.

Recently introduced on 28th and 29th Street line, New York City, by the Metropolitan Street Railway Company.

The above cut is of a 28 foot Compressed Air Motor Car hauling two trail cars in Chicago.



VIEW OF TRUCK OF THE NEW HARDIE AIR MOTOR CAR BODY REMOVED. THE STEEL STORAGE BOTTLES ARE SHOWN IN THE FOREGROUND. THE LARGE TANK IN THE CENTER IS THE REHEATER. THE ENGINES ARE ON THE OUTSIDE OF THE FRAME DIRECTLY OVER EACH RAIL.

Systems of Compressed Air Installation.

In the Hardie System the cars have 55 cubic feet of air storage, air being carried at 2500 pounds initial pressure in two nests of seven bottles each under the car and two long bottles within the car, placed longitudinally under the seats.

The air is reduced to 150 pounds per. square inch before entering the reheater and passing thence to the cylinders. The reservoirs within the cars are concealed and take up no passenger space.

Cars run one or two round trips without recharging, depending on the weight of traffic, weather conditions, and skill and judg--ment of the motorman.

On each platform are placed the operating devices, consisting of reversing levers,,throttle lever, air brake lever and the valve for shutting off air storage. A hand brake is also supplied for emergency.

The car seats thirty persons. The weight of the motor truck is 11000 pounds and total weight of car in working order 19000 pounds. The driving wheels 26 inches in diameter, are journaled in regular locomotive style and have the usual driving box spring suspension.

The relative positions of air reservoirs and reheaters are shown in cuts. When the air leaves the high pressure reservoir it passes through the pipe leading to the controller " stands" on the plat-forms where it is controlled by what is called the platform valve. From this point it passes to the reducing valve, which establishes the initial cylinder pressure of 150 pounds previously referred to, then from the reducing valve into the reheater before being receiv-

ed into the cylinders.

The reducing valve is a diaphram valve, specially constructed to deal with high pressures and , in addition to the ordinary action of such valves, a supplimentary action is brought about by reducing the air pressure that is normally kept in the chamber above the valve head. When it is desired to quickly accelerate under heavy load, a movement of the brake valve handle to a given position discharges the air from the chamber above valve head and thus increasing the value of the coil spring beneath the diaphram, opens the reducing valve in greater measure and temporarily increases the working pressure to 200 pounds while it is desirable to use that pressure in the cylinders.

The initial temperature of the fresh-charged water in the reheater is about 300 degrees F.

In this connection it may be said a car runs twice as far by heating the air as when the same amount of air was used cold.

The latest development of the Hardie improved cut-off valve gear is shown in side and end elevation. A supplimentary cut-off arrangement is used. The motion of the cut-off valve is obtained through a floating system of levers moved by the cross head and link jointly. The motion is primarilly a Stephenson link gear to operate the main valve.

The great advantage of having independent motors is generally recognized.

The impractability of using steam as a motive force for street cars is likewise conceded. The choice, therefore, narrows in the

present state of the art, to that of very heavy and expensive electric storage battery cars or compressed air motors, when independent units are considered. It is not inconceivable or even unlikely that there are in New York, and in many other cities of consequence, cross town streets where the interest on the first cost of placing an underground electric or a cable system in the maze of pipes and conduits there holding a prior claim would continuously exceed the actual cost of operating a compressed air system of traction, when large plant units are considered.

It is a noticeable feature of the operation of the cars now running on 28th. and 29th. streets that the noise of exhaust that was objectionable in the working of the Hoadley-Knight motors is practically eliminated.

The cars both in acceleration under heavy load and when running at speed, are probably the least noisy of all cars operating on street railroads unless the cable car be excepted. At first thought it would seem that in exhausting air from an initial cylinder pressure of 150 pounds per. square inch there would be a pronounced sound from the cylinders as in the case of the locomotive.

It is apparent, however, that in dealing with a permanent gas such as air, where the expansion may be carried to the limit without loss by condensation, and where the exhaust is practically limitless in area because no fire is to be forced, the noise of the exhaust may be reduced in proportion to the expansion of air and freedom of exhaust, and becomes, as in this instance practically nothing.

This system differs from the Hoadley-Knight system in the

position of the engines only.

In the Hoadley-Knight system the engines were between the rails and power transmitted to the wheels by crank shafts.

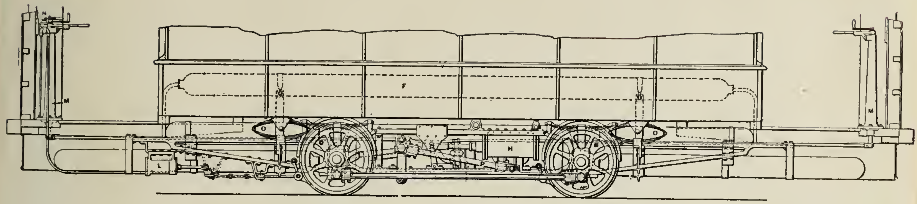


FIG. 2—ELEVATION OF CAR, SHOWING DETAILS OF EQUIPMENT.

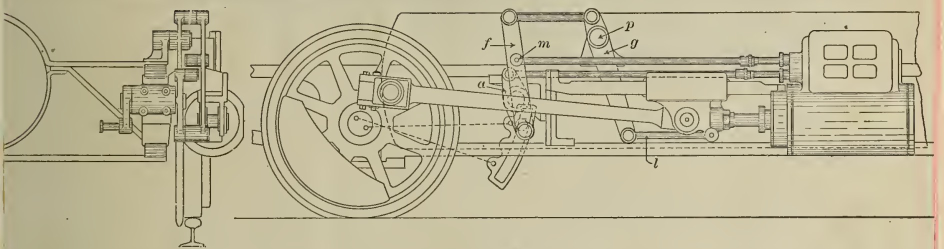


Fig. 3.—Hardie Air Motor.
Elevations Showing Valve Gear.

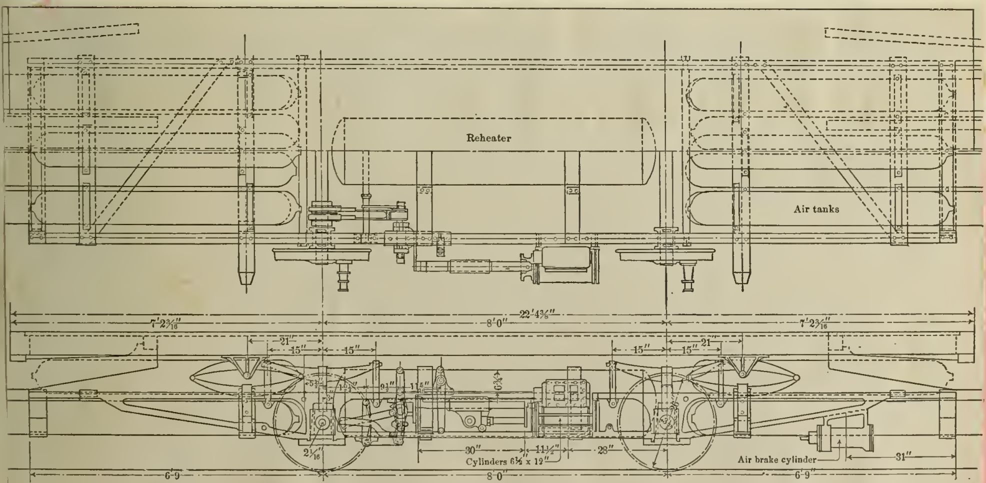


Fig. 2.—Hardie Compressed Air Motor.
Plan and Elevation.

The London Engineering Vol. 47, pages 163, 638, 685, 715 and Vol. 51 pages 327 and 419 and Vol. 58, page 313 describes the Popp system of compressed air in Paris. The first application of compressed air was to run clocks, using small cylinders with a piston. The cylinder is connected by tubes to the main air pipe. The impulse is given to the air in the mains every minute and in turn transmitted to each clock when the minute hand moves forward one space.

The plant was soon extended so as to furnish power for all sorts of purposes, ranging from the comparatively slight energy required for working a sewing machine, to the force necessary for driving printing machinery, electric light installations, elevators, etc.

To heat the air it is passed through a heating chamber where it is subjected to the action of a gas jet, and is also saturated by a spray of water which, it is claimed, nearly doubles the efficiency and prevents the formation of ice at the exhaust; a special type of engine, however, furnished with independent admission and exhaust valves, is being introduced to avoid the use of the heating device.

The heaters used by Mr. Popp were small cast iron stoves lined with fire clay heated by a gas jet or by a small coke fire.

Some results of experiments on heating are given. They were obtained from trials by Prof. Gutermuth. From these trials it was found that more than 70 per cent of the heat in the fuel was absorbed by the air and transformed into useful work.

Efficiency of Air Heating Stoves.

Nature of stove.	Heating surface. sq. ft.	Air heated per. hr. cu. ft.	Temperature of air in oven. Admission.	Exhaust.	Heat absorbed per. hr. Total.	Per. sq. ft. heating surface	Per. lb. coke.
Cast iron	14	20342	7	107	17900	1278	2032
Box stoves.	14	11054	7	184	17200	1228	2058
Wrt. iron coiled tubes.	46.3	38428	50	175	39200	830	2545

Table of Tests on Small Crank Steam Engines.

Engine used.	R. P. M.	B. H. P.	Temp. of air. Admission. Cent.	Exhaust. Cent.	Air consumption per. B. H. P. hr in cu. ft. Cold.	Heated.
2 H. P. Tayne.	242	3.77	25	-37	1186	
2 H. P. "	229	3.56	150			960
2 H. P. Journeaux.	169	2.10	10		1204	
2 H. P. "	148	2.27	150	0		695
1 H. P. "	283	1.035	150	34		845
1 H. P. Boulet.	149	1.10	165	18		815

The system employed in the propulsion of cars is the "Conti". The air is compressed to a relatively high pressure at a central station. It is then admitted to the main placed beneath the rails.

Branches lead the air nearly to the surface into automatic devices by which the car reservoirs can be charged at intervals along the line.

Value of Reheating Compressed Air Before Using as a Motive Power.

"Compressed Air" of October 1899 contains the following report on trials made at Magog, Quebec to test the economy effected by preheating compressed air by Prof. J. T. Nicolson.

These trials were made during the month of April 1899 at the Dominion Cotton Mills; Magog, Canada, where there is installed a 150 horse-power hydraulic air compressing plant on the system devised by C. H. Taylor of Montreal.

The trials were conducted under the auspices of Mr. Inslee, the Taylor Hydraulic Air Compressing Co., and the Dominion Cotton Mill Co. jointly, assisted by Prof. R. J. Burley of McGill University.

Experiments were made on five different methods of using compressed air in an ordinary steam engine of the Corliss type.

First. The air was supplied to the engine cold.

Second. Steam was injected into the air in the main pipe before supplying it to the engine.

Third. The air was injected into the water in a steam boiler and heated by mixing with the water and steam of the boiler before being supplied to the boiler.

Fourth. The air was blown upon the surface of the water in a steam boiler and heated by mixing with steam in same before being made to drive the engine.

Fifth. The air was passed through a tubular heating vessel and heated by a coke fire, afterward being used to work the engine.

For all the experiments the air was drawn at a pressure of 53 lbs. from the five inch main air pipe of the Taylor Air Compressor, which

supplies power to the mill, and was piped to a 12x30 Corliss engine supplied for the purpose of the trial by the Laurie Engine Co. of Montreal.

A friction brake was fitted on the fly-wheel of this engine and the engine in this way was worked up to its full power at about 75 R.P.M.

Connection was made to a Lancashire boiler seven feet in diameter by thirty feet long when it was desired to mix steam with the air for purposes of preheating.

When dry heating was resorted to, the air pipe was led through a heater on its way to the engine, having been previously blanked off from the steam boiler. This heater was designed by S. Nicolson and built by Messers The Laurie Engine Co. for these experiments, but as it was designed of such size as to heat the whole of the compressed air used in the mill, it was considerably larger than was required to heat the greatest quantity or air which could be used by the Corliss engine employed on the test.

Observations taken in the test without preheating were-

First. The temperature of air before entering engine.

Second. Temperature of air on leaving engine.

Third. The pressure of the entering air, indicator cards from each end of cylinder, revolutions and brake load.

The following are the results taken April 27th.1899 with cold air. Entering air 66.5 degrees F., exhaust air -41 degrees F., R.P.M. 74.6 with cut-off about 1/3 stroke. The I.H.P. was 27 and air used per hour 1671 lbs. or about 841 cu. ft. free air at 60.degrees F

per. I.H.P. hr.

On another trial made under the same conditions 850 cu. ft. of free air was used per. I.H.P. hr.

In experiments made with dry heating the following observations were made:-

Temperature of the air before entering the heater; after passing up first row of tubes; upon leaving heater; and before entering engine. Also temperature of furnace and flue gases.

Cards were taken,also revolutions and brake horse power.

With air entering heater at a pressure of 53.5 pounds gauge and 58.2 degrees F. it was raised to 225 degrees F. after passing first row of tubes and to 363 degrees F. upon leaving the heater, but owing to lack of covering on pipe it fell to 287 degrees F. before entering engine where the pressure was 52.8 pounds gauge.

With these conditions and same cut off as in trial No. 1 with cold air the I.H.P. being 26.7 and revolutions 70 per. min., 1310 pounds of air per. hour was used which gives a consumption of 640 cu. ft. of free air per I.H.P. hr. a reduction of 210 cu. ft. of free air per. I.H.P. hr. due to preheating, or a saving of 24.7 per. cent is effected in the quantity of air used.

Tests were also made to determine the economy by heating the air by mixing it with steam from a boiler before allowing it to do work in the engine.

By mixing from 10 to 13 pounds of steam per horse power with the air the quantity of air was reduced from 850 cu. ft. to 300 to 500 cu. ft. per I.H.P. hr.

This method of preheating is not so economical as dry heating nor is it suitable for powers less than 50 horse-power unless waste steam is available.

SERGEANT AIR REHEATER.

The accompanying cut represents the Sergeant Air Reheater in its simplest and most efficient form, the heater proper being made of two cast-iron shells, bolted together, having no tubes of any description to burn out or leak.

The heater is made in one size only, the extreme dimensions being 42 inches diameter by 54 inches high, the grate being 19 inches diameter.

From tests made with this heater it has been found capable of heating 340 cubic feet of free air per minute at 40 lbs. pressure to 360° F., giving a gain of 35 per cent. in the measured amount of work done by the air after passing through the heater, compared with the same volume of air when used cold.

A heater of this size will heat less air to a higher temperature, or more air to a lower temperature, than stated above; but, if it should be required to heat more than 400 cubic feet of free air per minute, to get the best economy, it is advisable to use the heaters in series, allowing about 400 cubic feet of free air per minute for each heater. The heater should be placed as near as possible to the point where the air is to be used, and the outlet pipe should be as short as possible and well covered, so that the air will retain its heat. Weight, 2,300 lbs.

Test of an Ingersoll Sargent, Class E, Air Compressor.

The object of this test was to determine the horse-power required to run the compressor and the efficiency of the compressor when compressing to different pressures.

To accomplish this purpose the compressor was run against pressures varying ten pounds at intervals of twenty-five minutes, during which time the pressure against the compressor was kept constant by means of a hand governed valve.

The revolutions of the compressor and engine were taken at intervals of five minutes and cards were taken from the engine and compressor simultaneously.

From this data the indicated horse-power of the two machines was calculated by the fillowing formula $\frac{PLAN}{33000} = $ I.H.P. in which P = mean pressure of card, L = length of stroke in feet, A = effective area of piston and N = number of revolutions per minute.

The I.H.P. was calculated for head and crank ends separately.

The constants for the 10x10 air compressor are, for head end $\frac{L.A.}{33000} = .001983$ and for crank end $\frac{L.A.}{33000} = .001923$.

The constants for the 10x10 Ide engine used are for head end $\frac{L.A.}{33000} = .001983$ and for crank end $\frac{L.A.}{33000} = .001913$.

Now, having the I.H.P. of both engine and compressor, the mechanical efficiency was found by dividing the I.H.P. of the compressor by the I.H.P. of the engine.

The flow of cooling water through the water jacket of the compressor was kept constant and measured by means of a meter and found to be

61.35 cubic feet per hour.

In order to show conditions under which test was run a thermometer was inserted in the pipe leading from the compressor to tank and temperature noted at intervals of five minutes as was the temperature of the room and outside air and steam pressure.

The following sheets contain the tabulated results and the original data showing conditions under which test was run; also characteristic cards from the engine and compressor.

The following photographs show the system of belting used, air receivers and reducing motions used.

No.	Time.	Engine R. P. M.	Comp. R. P. M.	Steam Pressure.	Air Press.	Temperatures Exhaust.	Out-side.	Room.
1.	8:00	301	151	110	0	80	45	76
2.	8:05	297	150	111	0	80	45	76
3.	8:10	299	151	108	0	80	45	76
4.	8:15	300	152	107	0	80	45	77
5.	8:20	300	152	104	0	80	45	78
6.	8:25	298	151	104	10	140	45	77
7.	8:30	297	150	105	10	141	45	77
8.	8:35	300	152	105	10	142	45	78
9.	8:40	300	151	106	10	140	45	78
10.	8:45	300	151	104	10	139	45	77
11.	8:50	300	151	104	20	170	45	78
12.	8:55	298	150	105	20	174	45	78
13.	9:00	302	152	107	20	175	45	78
14.	9:05	300	151	108	20	176	45	78
15.	9:10	300	151	108	20	176	45	78
16.	9:15	298	150	106	30	199	45	78
17.	9:20	299	150	105	30	203	45	78
18.	9:25	299	150	108	30	204	45	78
19.	9:30	299	150	113	30	205	45	78
20.	9:35	299	150	105	30	204	45	78
21.	9:40	299	151	103	40	231	45	78
22.	9:45	299	150	108	40	232	45	78
23.	9:50	299	151	106	40	233	45	78
24.	9:55	300	151	106	40	233	45	77

No.	Time.	Engine R. P. M.	Comp. R. P. M.	Steam Pressure.	Air Press.	Temperatures. Exhaust.	Out-side.	Room.
25.	10:00	299	151	107	40	233	45	78
26.	10:05	299	150	106	50	252	45	77
27.	10:10	299	151	106	50	253	45	77
28.	10:15	299	150	108	50	253	45	78
29.	10:20	299	151	105	50	253	45	78
30.	10:25	299	151	103	50	254	45	77
31.	10:30	299	151	108	60	268	45	78
32.	10:35	300	151	107	60	270	45	78
33.	10:40	299	151	109	60	270	45	78
34.	10:45	299	150	109	60	271	45	78
35.	10:50	299	150	108	60	272	45	78
36.	10:55	299	150	108	70	279	45	78
37.	11:00	301	151	109	70	282	45	78
38.	11:05	299	150	108	70	282	45	78
39.	11:10	299	151	108	70	282	45	78
40.	11:15	298	150	108	70	282	45	78
41.	11:20	298	150	108	80	286	45	78
42.	11:25	298	150	108	80	287	45	78
43.	11:30	298	150	108	80	288	45	78
44.	11:35	299	150	109	80	289	45	78
45.	11:40	298	150	105	80	290	45	78
46.	11:45	298	150	108	90	297	45	78
47.	11:50	298	151	108	90	297	45	78
48.	11:55	298	150	103	90	297	45	78

No.	Time	Engine. R. P. M.	Comp. R. P. M.	Steam Pressure.	Air Press.	Temperatures. Exhaust.	Out side.	Room.
49.	12:00	298	151	103	90	298	42	78
50.	12:05	298	150	103	90	298	42	78
51.	12:10	299	150	100	100	310	42	78
52.	12:15	299	150	100	100	311	41	79
53.	12:20	299	151	100	100	311	41	78
54.	12:25	298	150	103	100	312	41	78
55.	12:30	298	150	101	100	312	41	78

No.	Time.	Engine I.H.P.	Compressor. I.H.P.	Mech. Eff. %	Average Mech. Eff. %	Air Press lbs. per sq. in.
1.	8:00	8.36				0
2.	8:05	7.82				0
3.	8:10	7.63				0
4.	8:15	8.71				0
5.	8:20	7.79				0
6.	8:25	13.16	7.04	53.3		10
7.	8:30	14.49	6.90	47.6		10
8.	8:35	13.78	7.15	51.9	50.7	10
9.	8:40	13.78	7.12	51.6		10
10.	8:45	14.42	7.12	49.3		10
11.	8:50	18.68	10.02	53;5		20
12.	8:55	17.11	10.50	61.3		20
13.	9:00	16.14	10.11	62.9	57.7	20
14.	9:05	18.14	10.00	55.1		20
15.	9:10	17.89	10.02	56.0		20
16.	9:15	19.39	12.40	63.9		30
17.	9:20	19.55	12.27	62.7		30
18.	9:25	19.10	12.25	64.1	62.2	30
19.	9:30	20.64	12;32	59.6		30
20.	9:35	19.98	12;20	61.0		30
21.	9:40	20.97	14.31	68.2		40
22.	9:45	20.99	14.04	66.8		40
23.	9;50	20.24	14.49	71.5	68.8	40
24.	9:55	20.61	14.45	70.1		40

No.	Time.	Engine I. H. P.	Compressor I. H. P.	Mech. Eff. %	Average Mech. Eff. %	Air Press. lbs. per. sq. in.
25.	10:00	20.97	14.14	67.5		40
26.	10:05	21.64	13.74	63.4		50
27.	10:10	23.24	15.17	65.2		50
28.	10:15	22.50	15.95	70.9	67.0	50
29.	10:20	21.68	15.01	60.2		50
30.	10:25	22.32	15.17	66.4		50
31.	10:30	22.75	15.88	69.8		60
32.	10:35	22.28	16.77	75.2		60
33.	10:40	23.52	16.24	69.0	70.1	60
34.	10:45	22.54	15.77	69.9		60
35.	10:50	23.67	15.78	66.8		60
36.	10:55	26.64	17.89	67.1		70
37.	11:00	24.77	15.68	63.3		70
38.	11:05	25.57	16.12	63.0	66.3	70
39.	11:10	26.08	17.14	65.7		70
40.	11:15	23.76	17.12	72.0		70
41.	11:20	25.99	17.35	66.7		80
42.	11:25	23.41	18.23	77.8		80
43.	11:30	23.37	17.53	75.0	75.4	80
44.	11:35	26.92	18.79	68.3		80
45.	11:40	26.76	18.58	69.4		80
46.	11:45	28.70	20.17	70.3		90
47.	11:50	27.35	20.31	74.2		90
48.	11:55	26.31	18.80	71.4	70.2	90

No.	Time	Engine I.H.P.	Compressor I.H.P.	Mech. Eff. %	Average Mech. Eff. %	Air Press. lbs. per sq. in.
49.	12:00	27.35	18.35	67.1		90
50.	12:05	27.54	18.77	68.1		90
51.	12:10	29.53	21.22	71.8		100
52.	12:15	29.52	20.52	69.5		100
53.	12:20	29.35	21.22	72.3	71.7	100
54.	12:25	29.70	21.[illegible]6	72.6		100
55.	12:30	30.01	21.50	71.6		100

After test number one was completed the clearance was found unequal as shown by the cards. This was adjusted by lengthening the piston rod until correct position was obtained as shown by testing with indicator.

Test number two was then run with the following results.

10-2-00-2M-O

UNIVERSITY OF ILLINOIS
MECHANICAL ENGINEERING LABORATORY

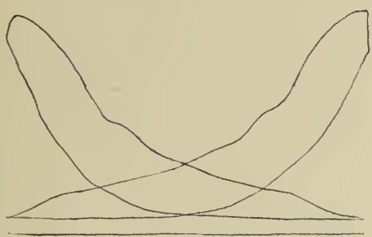
BOILER PRES. 108
R. P. M. 299
SCALE 60

CARD NO. 38
END
CYLINDER 10 × 10

A = .97 □"
M.E.P. = 21.9
I.H.P. = 12.67

A = .96 □"
M.E.P. = 21.66
I.H.P. = 12.9

Crosby 2-inch Drum



1-15-00-1M-O

UNIVERSITY OF ILLINOIS
MECHANICAL ENGINEERING LABORATORY

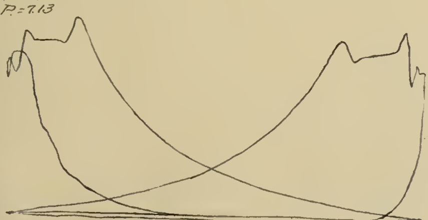
BOILER PRES. 70
R. P. M. 150
SCALE 60

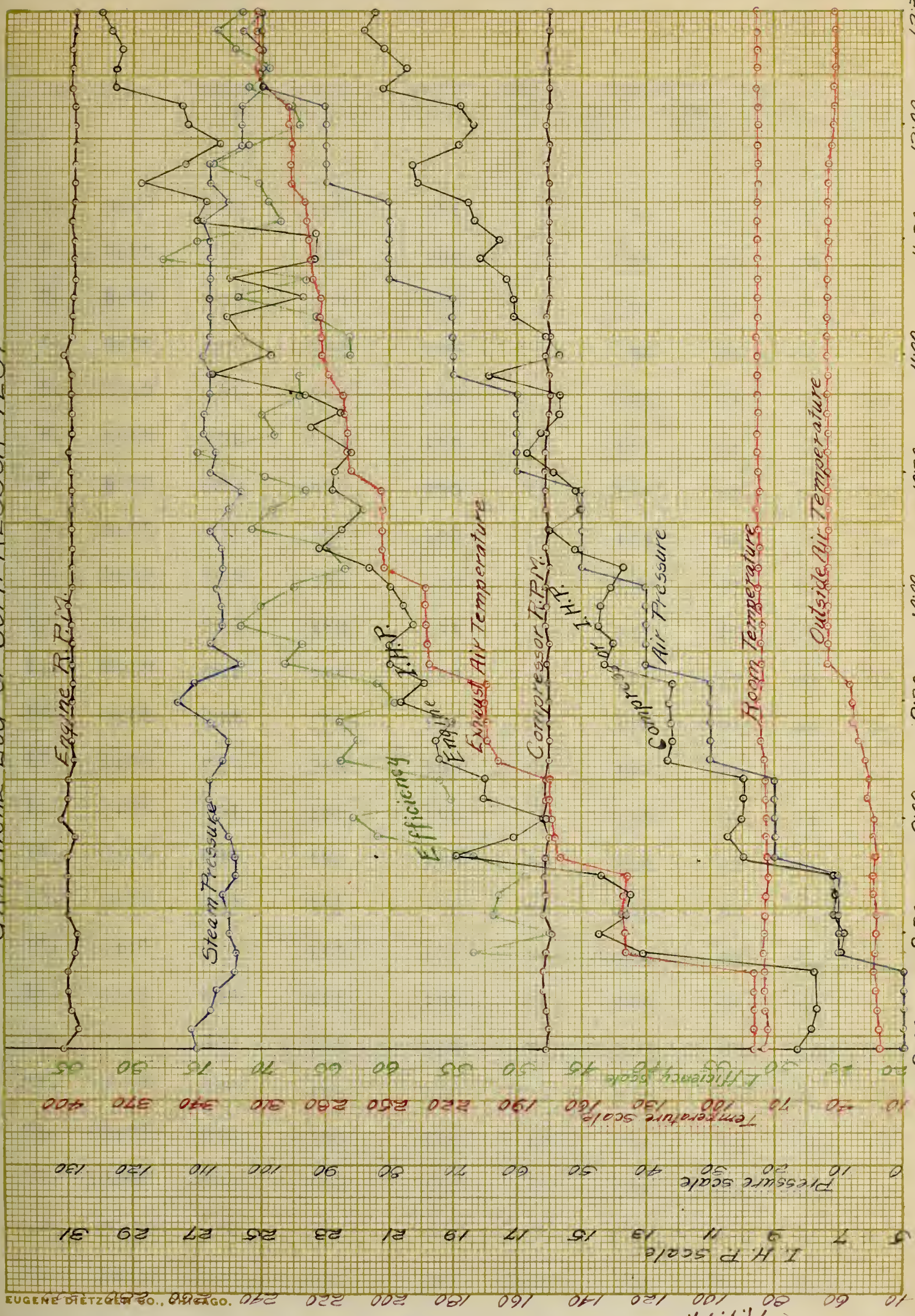
CARD NO. 38
END
CYLINDER 10 × 10

A = 1.23 □"
M.E.P. = 24
I.H.P. = 7.13

A = 1.62 □"
M.E.P. = 31.2
I.H.P. = 8.99

Thompson 1½-inch Drum




GRAPHICAL LOG OF COMPRESSOR TEST
Engine R.P.M.
Steam Pressure
Efficiency
Engine I.H.P.
Exhaust Air Temperature
Compressor R.P.M.
Compressor I.H.P.
Air Pressure
Room Temperature
Outside Air Temperature
8:00
8:30
9:00
9:30
10:00
10:30
11:00
11:30
12:00
12:30
Efficiency scale
Temperature scale
Pressure scale
I. H. P. scale
R.P.M.
EUGENE DIETZGEN CO., CHICAGO.

No.	Time.	Engine R. P. M.	Comp. R. P. M.	Steam Press.	Air Press.	Temperatures. Exhaust Air.	Out side.	Room.	Exhaust water.
1.	8:20	302	153	111	0	90	26	72	56
2.	8:25	299	151	109	0	86	26	72	56
3.	8:30	301	152	109	0	87	26	72	55
4.	8:35	301	152	108	0	86	26	72	55
5.	8:40	301	144	109	0	84	26	72	55
6.	8:45	301	151	110	10	141	26	72	55
7.	8:50	299	152	110	10	146	26	72	55
8.	8:55	301	150	110	10	144	26	72	56
9.	9:00	299	151	110	10	143	27	72	56
10.	9:05	299	152	111	10	142	27	72	56
11.	9:10	301	151	110	20	172	27	72	56
12.	9:15	298	150	110	20	178	27	72	56
13.	9:20	299	152	110	20	178	27	73	56
14.	9:25	301	151	110	20	180	27	74	56
15.	9:30	298	150	110	20	180	27	74	56
16.	9:35	299	151	110	30	200	28	74	56
17.	9:40	298	150	107	30	204	28	74	56
18.	9:45	299	151	105	30	206	28	74	57
19.	9:50	298	150	110	30	208	28	74	57
20.	9:55	298	151	109	30	210	28	74	57
21.	10:00	299	150	110	40	221	28	75	57
22.	10;05	298	150	110	40	224	28	75	57
23.	10:10	299	150	107	40	225	28	75	57
24.	10:15	298	150	109	40	226	28	75	57

No.	Time.	Engine R. P. M.	Comp. R. P. M.	Steam Press.	Air Press.	Temperatures. Exhaust Air.	Out side.	Room.	Exhaust water.
25.	10:20	298	150	109	40	227	28	75	57
26.	10:25	297	149	108	50	244	28	76	58
27.	10:30	297	150	110	50	249	28	76	58
28.	10:35	298	150	102	50	250	28	76	59
29.	10:40	298	150	110	50	252	28	76	58
30.	10:45	299	149	110	50	252	28	76	58
31.	10:50	300	151	110	60	262	28	76	58
32.	10:55	301	151	110	60	267	28	76	58
33.	11:00	298	150	110	60	267	28	76	58
34.	11:05	298	150	110	60	270	28	76	59
35.	11:10	298	150	110	60	270	28	76	59
36.	11:15	297	149	110	70	275	28	77	59
37.	11:20	298	150	110	70	278	28	77	59
38.	11:25	299	151	110	70	280	28	77	59
39.	11:30	297	149	110	70	280	29	78	60
40.	11:35	300	151	110	70	280	29	78	60
41.	11:40	298	150	110	80	286	29	78	60
42.	11:45	297	149	110	80	288	29	78	60
43.	11:50	297	149	110	80	290	29	78	61
44.	11:55	298	151	110	80	290	29	78	61
45.	12:00	296	149	110	800	292	29	78	61
46.	12:05	298	150	110	90	302	29	78	62
47.	12:10	297	149	110	90	304	29	78	61
48.	12:15	297	149	107	90	304	29	78	61

No.	Time.	Engine R. P. M.	Comp. R. P. M.	Steam Press.	Air Press.	Temperatures. Exhaust Air.	Out side.	Room.	Exhaust water.
49.	12:20	297	149	107	90	303	29	78	61
50.	12:25	297	149	108	90	304	30	78	61
51.	12:30	297	150	109	100	305	30	78	61
52.	12:35	297	149	107	100	308	30	78	61
53.	12:40	299	151	107	100	310	30	78	62
54.	12:45	297	149	108	100	311	30	78	61
55.	12:50	298	150	108	100	312	30	78	61

No.	Time.	Engine I.H.P.	Compress. I.H.P.	Mech. Eff. %.	Average Mech. Eff. %	Air Press. lbs. per sq. in.
1.	8:20	10.2				0
2.	8:25	8.4				0
3.	8:30	9.3				0
4.	8:35	9.4				0
5.	8:40	9.9				0
6.	8:45	16.1	6.71	41.6		10
7.	8:50	16.2	6.61	40.8		10
8.	8:55	15.6	6.65	42.6	42.9	10
9.	9:00	14.9	6.75	45.3		10.
10.	9:05	15.4	8.87	44.6		10
11.	9:10	17.2	9.01	52.3		20
12.	9:15	17.2	8.87	51.5		20
13.	9:20	17.6	8.88	50.4	51.9	20
14.	9:25	16.9	9.42	55.7		20
15.	9:30	17.4	8.68	50.0		20
16.	9:35	18.6	10.82	58.2		30
17.	9:40	19.6	10.97	54.8		30
18.	9:45	18.9	10.82	57.1	55.8	30
19.	9:50	19.4	10.82	55.4		30
20.	9.55	19.3	10.74	55.7		30
21.	10:00	21.4	12.27	57.3		40
22.	10:05	20.3	12.15	59.8		40
23.	10:10	20.8	12.55	60.3	59.0	40
24.	10:15	20.3	12.30	60.6		40

No.	Time.	Engine I. H. P.	Compress. I. H. P.	Mech. Eff. %	Average Mech. Eff. %	Air Press. lbs. per. sq. in.
25.	10:20	21.4	12.28	57.3		40
26.	10:25	22.6	13.78	58.3		50
27.	10:30	22.7	13.44	59.2		50
28.	10:35	23.3	13.64	58.5	60.3	50
29.	10:40	21.8	13.72	62.9		50
30.	10.45	22.3	14.04	62.9		50
31.	10:50	24.5	14.62	61.0		60
32.	10:55	24.5	14.46	59.0		60
33.	11:00	23.2	14.87	64.1	61.8	60
34.	11:05	23.9	14.62	61.3		60
35.	11:10	23.2	14.82	63.8		60
36.	11:15	24.9	17.45	70.0		70
37.	11:20	24.2	17.17	70.9		70
38.	11:25	25.4	17.25	67.9	68.7	70
39.	11:30	23.9	16.73	70.0		70
40.	11:35	25.1	16.31	65.0		70
41.	11:40	25.9	17.22	66.4		80
42.	11:45	27.6	16.52	59.8		80
43.	11:50	26.4	17.44	66.0	63.7	80
44.	11:55	25.8	17.90	69.4		80
45.	12:00	25.7	16.17	62.9		80
46.	12:05	27.9	18.32	65.6		90
47.	12.10	27.8	18.16	65.3		90
48.	12:15	28.8	17.35	60.2	63.7	90

No.	Time.	Engine I. H. P.	Compress. I. H. P.	Mech. Eff. %	Average Mech. Eff. %	Air Press. lbs. per. sq. in.
49.	12:20	27.7	17.96	64.8		90
50.	12:25	26.9	16.86	62.6		90
51.	12:30	27.3	19.30	70.7		100
52.	12:35	27.8	19.10	68.7		100
53.	12:40	27.3	18.50	67.8	68.1	100
54.	12:45	27.1	20.00	73.8		100
55.	12:50	30.3	18.13	59.8		100

In test number two the head end card was found to be defective so the exhaust valves were examined, and the regulating by-pass was closed and test number three was conducted with satisfactory results.

Crosby 2-inch Drum

10-2-00-2M-O

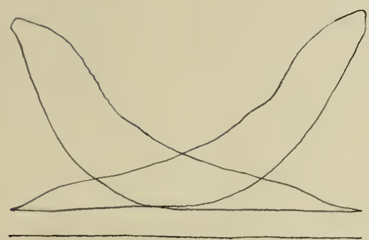
UNIVERSITY OF ILLINOIS
MECHANICAL ENGINEERING LABORATORY

BOILER PRES. 110
R. P. M. 299
SCALE 60

Area .97 □"
M.E.P. 22.17
I.H.P. 13.1

CARD NO. 38
END
CYLINDER 10 X 10

Area .94 □"
M.E.P.=21.48
I.H.P.- 12.3



Thompson 1½-inch Drum

1-15-00-1M-O

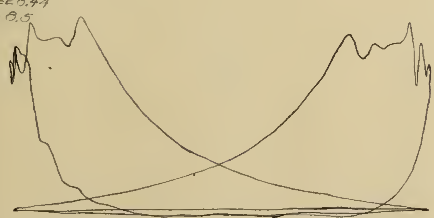
UNIVERSITY OF ILLINOIS
MECHANICAL ENGINEERING LABORATORY

BOILER PRES. 70
R. P. M. 151
SCALE 60

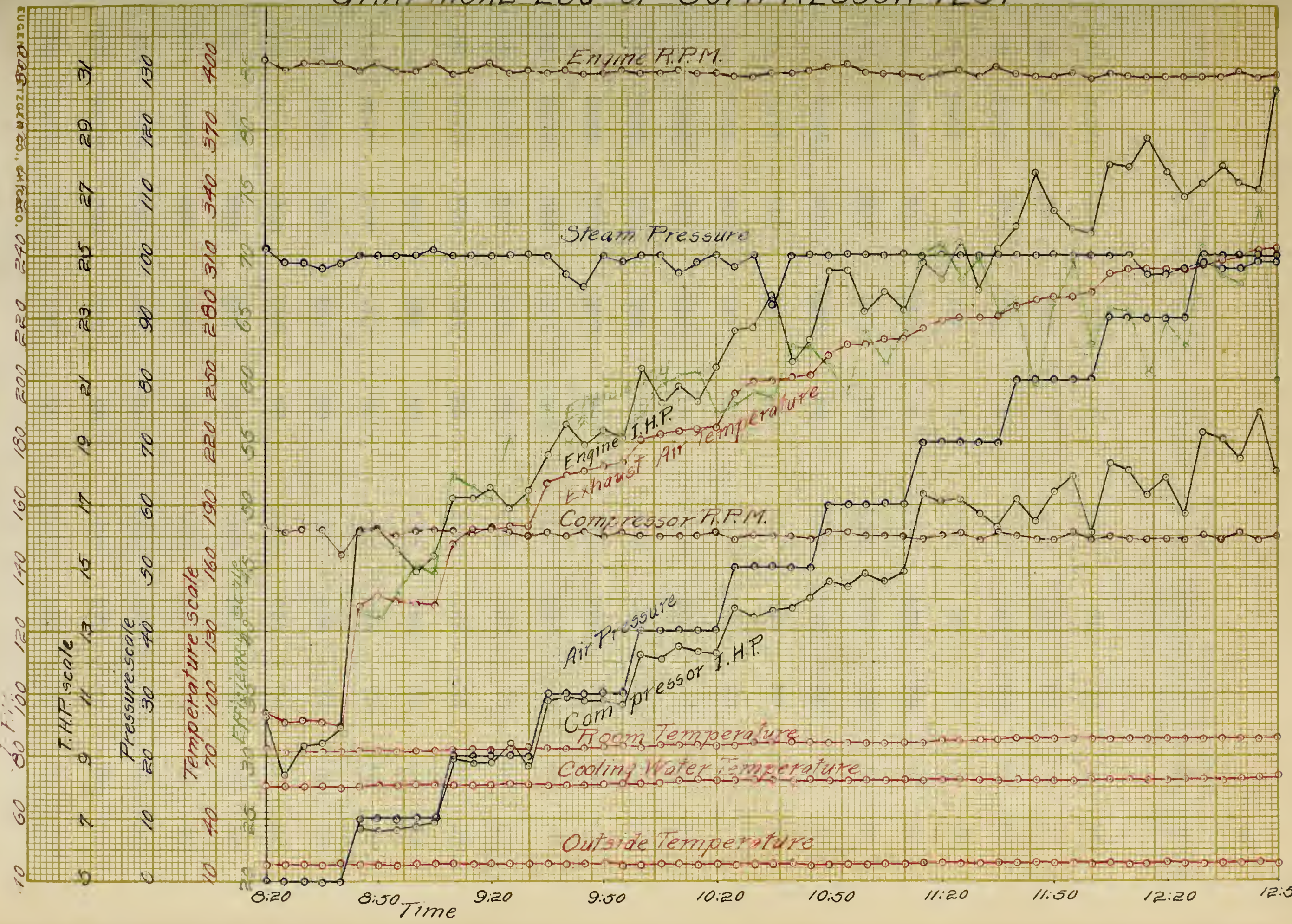
Area - 1.46
M.E.P. =28.44
I.H.P. - 8.5

CARD NO. 39
END
CYLINDER 10 X 10

Area = 1.55
M.E.P. - 30.19
I.H.P. - 8.75



GRAPHICAL LOG OF COMPRESSOR TEST



No.	Time.	Engine R.P.M.	Comp. R.P.M.	Air Press.	Steam Press.	Temperatures. Exhaust Air.	Out side.	Room.	Exhaust water.
1.	8:00	300	152	0	110	90	39	78	55
2.	8:05	299	152	0	108	88	39	77	55
3.	8:10	300	152	0	106	87	39	77	55
4.	8:15	300	152	0	108	85	39	77	55
5.	8:20	300	153	0	106	138	39	77	55
6.	8:25	298	151	10	105	140	38	78	55
7.	8:30	300	153	10	107	142	38	78	55
8.	8:35	300	153	10	110	140	37	79	55
9.	8:40	301	153	10	108	140	36	79	55
10.	8:45	301	152	10	110	140	36	79	55
11.	8:50	300	152	20	108	172	36	79	55
12.	8:55	300	152	20	105	178	36	79	55
13.	9:00	300	151	40	105	179	35	80	55
14.	9:05	300	151	20	108	180	35	80	55
15.	9:10	300	152	20	110	180	35	80	55
16.	9:15	299	151	30	110	198	35	80	55
17.	9:20	299	151	30	114	202	35	80	56
18.	9:25	299	151	30	113	204	34	80	56
19.	9:30	298	150	30	110	204	34	80	56
20.	9:35	299	151	30	107	204	34	80	56
21.	9:40	299	150	40	110	218	34	80	56
22.	9:45	299	151	40	110	220	34	80	56
23.	9:50	298	150	40	110	220	34	80	56
24.	9:55	298	151	40	110	224	33	80	57

No.	Time.	Engine R.P.M.	Compress. R.P.M.	Air Press.	Steam Press.	Temperatures. Exhaust Air.	Out side.	Room.	Exhaust water
25.	10:00	298	150	40	110	224	33	81	57
26.	10:05	298	150	50	107	242	33	81	57
27.	10:10	299	150	50	112	245	32	81	57
28.	10:15	299	150	50	112	248	32	81	57
29.	10:20	299	151	50	113	249	32	81	57
30.	10:25	299	151	50	112	250	32	81	57
31.	10:30	298	150	60	114	267	32	81	57
32.	10:35	298	150	60	112	270	32	82	58
33.	10:40	298	149	60	112	270	32	82	58
34.	10:45	298	150	60	114	272	32	82	58
35.	10:50	299	150	60	115	272	32	82	58
36.	10:55	299	150	70	115	280	32	82	58
37.	11:00	298	149	70	111	282	32	82	58
38.	11:05	299	149	70	110	284	31	83	58
39.	11:10	298	149	70	108	284	31	83	58
40.	11:15	298	149	70	105	284	30	83	58
41.	11:20	298	150	80	105	288	30	83	58
42.	11:25	298	150	80	113	292	30	83	59
43.	11:30	298	150	80	114	293	30	83	59
44.	11:35	298	150	80	112	293	30	83	59
45.	11:40	298	150	80	113	294	30	83	59
46.	11:45	299	150	90	113	298	30	83	59
47.	11:50	299	150	90	112	300	29	83	59
48.	11:55	299	150	90	112	302	29	83	60

No.	Time.	Engine R.P.M.	Compress. R.P.M.	Air Press.	Steam Press.	Temperatures. Exhaust Air.	Out side.	Room.	Exhaust water.
49.	12:00	299	150	90	110	302	28	83	60
50.	12:05	299	150	90	110	304	28	83	60
51.	12:10	299	151	100	114	310	28	83	60
52.	12:15	299	150	100	113	312	28	83	60
53.	12:20	299	150	100	114	314	28	83	60
54.	12:25	299	150	100	114	314	28	83	60
55.	12:30	299	150	100	112	314	28	83	60

No.	Time.	Engine I. H. P.	Compress. I. H. P.	Mech. Eff. %	Average Mech. Eff. %	Air Press. lbs. per. sq. in.
1.	8:00	7.10				0
2.	8:05	7.44				0
3.	8:10	6.69				0
4.	8:15	7.68				0
5.	8:20	7.34				0
6.	8:25	12.25	6.66	54.4		10
7.	8:30	10.81	6.75	62.5		10
8.	8:35	12.48	6.56	52.5	56.38	10
9.	8:40	12.23	6.89	56.3		10
10.	8:45	11.63	6.54	56.2		10
11.	8:50	16.34	9.72	59.4		20
12.	8:55	15.32	9.51	62.1		20
13.	9:00	14.53	9.56	65.8	61.54	20
14.	9:05	15.44	9.55	61.9		20
15.	9:10	16.21	9.64	59.5		20
16.	9:15	18.87	11.54	61.2		30
17.	9:20	19.13	11.69	61.2		30
18.	9:25	18.63	11.78	63.2	63.2	30
19.	9:30	18.01	11.69	64.9		30
20.	9:35	17.44	11.61	65.5		30
21.	9:40	20.80	13.38	64.4		40
22.	9:45	20.66	12.94	62.7		40
23.	9:50	20.46	13.44	65.7	65.2	40
24.	9:55	20.73	13.75	66.4		40

No.	Time.	Engine I.H.P.	Compress. I.H.P.	Mech. Eff.%	Average Mech.Eff.%	Air Press. lbs. per. sq. in.
25.	10:00	20.46	13.66	66.8		40
26.	10:05	21.77	14.90	68.5		50
27.	10:10	21.78	14.16	65.1		50
28.	10:15	21.94	15.23	69.4	68.5	50
29.	10:20	21.94	15.20	69.2		50
30.	10:25	21.70	15.25	70.3		50
31.	10:30	23.17	17.18	74.1		60
32.	10:35	23.80	17.33	72.8		60
33.	10:40	23.13	17.13	74.0	72.4	60
34.	10:45	24.79	16.99	68.6		60
35.	10:50	23.62	17.13	72.5		60
36.	10:55	26.20	18.25	69.7		70
37.	11:00	24.68	18.14	73.5		70
38.	11:05	26.45	18.02	68.2	71.48	70
39.	11:10	25.63	18.02	70.3		70
40.	11:15	23.93	18.19	76.0		70
41.	11:20	26.11	19.28	73.8		80
42.	11:25	26.49	19.30	72.8		80
43.	11:30	27.13	19.22	70.8	72.74	80
44.	11:35	25.77	19.22	74.6		80
45.	11:40	27.01	19.37	71.7		80
46.	11:45	26.43	20.73	78.5		90
47.	11:50	27.44	20.58	75.0		90
48.	11:55	27.48	20.47	74.5	76.04	90

No.	Time.	Engine I.H.P.	Compress. I.H.P.	Mech. Eff.%	Average Mech. Eff.%	Air Press. lbs. per. sq. in..
49.	12:00	26.25	20.41	77.8		90
50.	12:05	27.57	20.48	74.4		90
51.	12.10	28.45	21.85	76.8		100
52.	12:15	28.61	21.20	74.1		100
53.	12.20	28.23	21.11	74.8	76.1	100
54.	12;25	27.08	21.28	78.6		100
55.	12.30	27.84	21.23	76.2		100

10-2-00-2M-O

UNIVERSITY OF ILLINOIS
MECHANICAL ENGINEERING LABORATORY

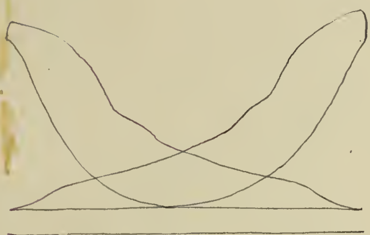
BOILER PRES. 110
R. P. M. 299
SCALE 60

Area - 1.06 □"
M.E.P.=23.39
I.H.P.=13.85

CARD NO. 39
END
CYLINDER 10 X 10

Area = 1. □"
M.E.P.= 22.06
I.H.P.= 12.6

Crosby 2-inch Drum



1-15-00-1M-O

UNIVERSITY OF ILLINOIS
MECHANICAL ENGINEERING LABORATORY

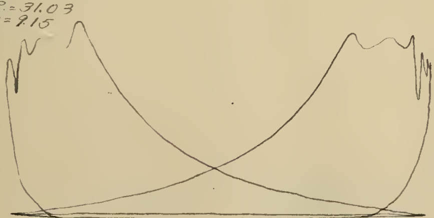
BOILER PRES. 70
R. P. M. 149
SCALE 60

Area= 1.6 □"
M.E.P.=31.03
I.H.P.=9.15

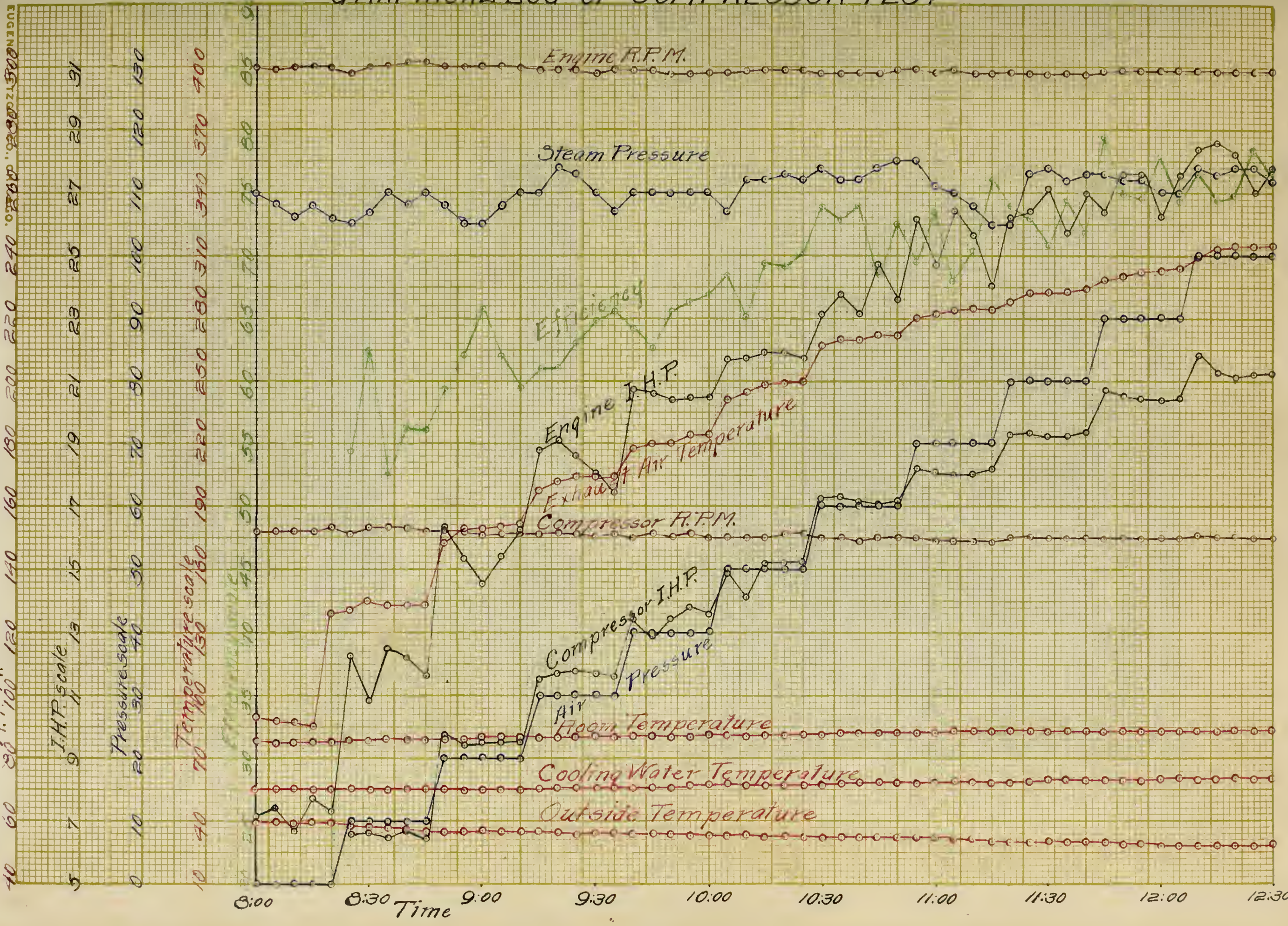
CARD NO. 39
END
CYLINDER 10 X 10

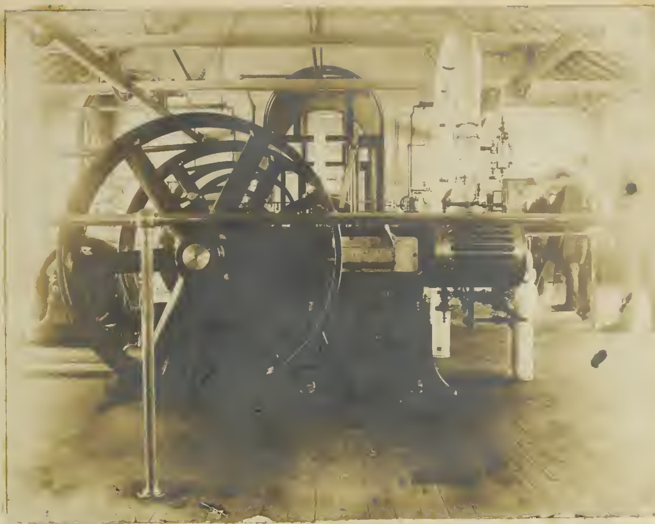
Area=1.6 □"
M.E.P.=31.03
I.H.P.=8.87

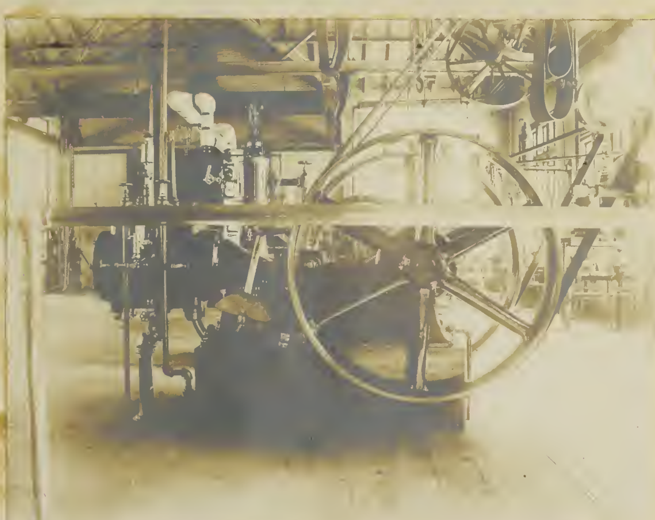
Thompson 1½-inch Drum

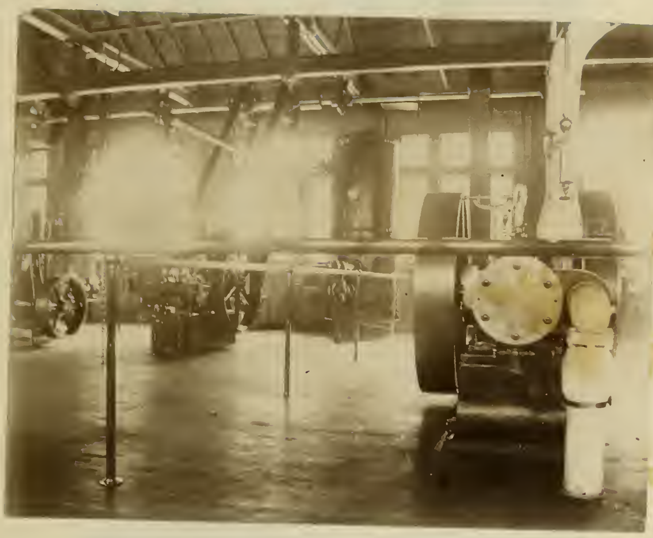


GRAPHICAL LOG OF COMPRESSOR TEST









Efficiency Test of Ingersoll-Sargent Duplex Compound Air Compressor

Class H, P. and E. shops, Urbana Illinois.

The object of this test was to determine the amount of power necessary to run the machine and also the efficiency with which the air compression was effected. The test was run while the machine was working under ordinary conditions. The machine supplies air for the entire shops. The test was run for three hours, from nine A.M. until twelve M. The readings and cards were taken simultaneously every five minutes. Revolutions were recorded every minute by means of a continuous counter.

The following readings were taken with each set of cards; time, steam-pressure, high air pressure, low air pressure, inlet air temperature, room temperature and R.P.M. The horse power devoloped by the various cylinders was found and then the mechanical efficiency was calculated.

Engine Constants.

$\frac{PLAN}{33000}$ H.P. $\frac{L.A.}{33000}$ constant.

Steam cylinders; crank end $\frac{LA}{33000}$ = .0019039, head end $\frac{LA}{33000}$ = .0019225.

High pressure air, crank end $\frac{LA}{33000}$ = .0019225, head end $\frac{LA}{33000}$ = .0019832.

Low pressure air, crank end $\frac{LA}{33000}$ = .0050163, head end, $\frac{LA}{33000}$ = .005077.

The following are the original data and results:

No.	Time.	Steam Pressure.	Air Pressure. High.	Air Pressure. Low.	Temperatures. Inlet Air.	Temperatures. Room.	R. P. M.
1.	9:00	75	116	26	17	83	56
2.	9:05	75	115	26	17	83	55
3.	9:10	78	120	27	17	83	59
4.	9:15	76	120	27	18	83	44
5.	9:20	75	120	27	18	83	44
6.	9:25	75	110	25	19	84	56
7.	9:30	73	110	26	19	84	49
8.	9:35	72	105	26	19	84	50
9.	9:40	75	108	26	19	84	50
10.	9:45	77	115	26	19	85	47
11.	9:50	78	120	27	19	86	55
12.	9:55	78	125	27	19	86	49
13.	10:00	78	128	27	19	86	48
14.	10:05	75	130	27	19	86	43
15.	10:10	75	120	27	19	88	50
16.	10:15	75	125	27	19	88	52
17.	10:20	72	115	27	19	84	45
18.	10:25	73	118	27	19	82	49
19.	10:30	70	115	27	20	81	44
20.	10:35	72	112	27	20	81	55
21.	10:40	78	117	27	20	81	67
22.	10:45	75	120	27	20	79	47
23.	10:50	74	115	27	20	80	63
24.	10:55	75	125	27	20	79	51

No.	Time.	Steam Pressure.	Air Pressure. High.	Low.	Temperatures. Inlet Air.	Room.	R. P. M.
25.	11:00	75	127	27	20	79	42
26.	11:05	81	130	27	21	81	60
27.	11:10	81	140	28	21	80	54
28.	11:15	76	132	27	21	79	45
29.	11:20	74	118	27	22.	76	51
30.	11:25	78	130	27	22.	78	54
31.	11:30	76	133	28	22	77	44
32.	11:35	78	135	28	22	80	46
33.	11:40	78	133	27	22	81	53
34.	11:45	72	125	28	24	80	41
35.	11:50	76	122	27	26	81	56
36.	11:55	76	130	27	28	82	50
37.	12:00	78	135	28	28	80	49

Time.	R. P. M.	Time.	R. P. M.	Time.	R. P. M.	Time.	R. P. M.
9:00	56	9:24	57	9:48	54	10:12	55
9:01	56	9:25	56	9:49	57	10:13	50
9:02	57	9:26	56	9:50	55	10:14	51
9:03	54	9:27	51	9:51	53	10:15	52
9:04	55	9:28	50	9:52	49	10:26	52
9:05	55	9:29	50	9:53	49	10:17	51
9:06	58	9:30	49	9:54	49	10:18	50
9:07	57	9:31	45	9:55	49	10:19	50
9:08	63	9:32	41	9:56	48	10:20	45
9:09	61	9:33	42	9:57	46	10:21	43
9:10	59	9:34	44	9:58	47	10:22	44
9:11	53	9:35	50	9:59	49	10:23	45
9:12	51	9:36	50	10:00	48	10:24	46
9:13	46	9:37	52	10:01	49	10:25	49
9:14	44	9:38	49	10:02	46	10:26	51
9:15	44	9:39	50	10:03	43	10:27	52
9:16	46	9:40	50	10:04	43	10:28	50
9:17	47	9:41	50	10:05	43	10:29	48
9:18	49	9:42	47	10:06	49	10:30	44
9:19	43	9:43	44	10:07	51	10:31	45
9:20	44	"9:44	43	10:08	52	10:32	49
9:21	46	9:45	47	10:09	58	10:33	56
9:22	51	9:46	51	10:10	50	10:34	55
9:23	57	9:47	53	10:11	53	10:35	53

Time.	R. P. M.	Time.	R. P. M.	Time.	R. P. M.	Time.	R. P. M.
10:36	53	11:00	42	11:24	60	11:48	53
10:37	57	11:01	45	11:25	54	11:49	55
10:38	62	11:02	45	11:26	55	11:50	56
10:39	66	11:03	48	11:27	51	11:51	54
10:40	67	11:04	53	11:28	48	11:52	53
10:41	62	11:05	60	11:29	45	11:53	48
10:42	65	11:06	64	11:30	44	11:54	48
10:43	55	11:07	65	11:31	47	11:55	50
10:44	56	11:08	64	11:32	47	11:56	51
10:45	47	11:09	58	11:33	44	11:57	53
10:46	52	11:10	54	11:34	48	11:58	44
10:47	51	11:11	49	11:35	46	11:59	50
10:48	51	11:12	48	11:36	44	12:00	49
10:49	53	11:13	44	11:37	44		
10:50	63	11:14	43	11:38	48		
10:51	44	11:15	45	11:39	52		
10:52	52	11:16	51	11:40	53		
10:53	53	11:17	48	11:41	52		
10:54	52	11:18	50	11:42	51		
10:55	51	11:19	50	11:43	47		
10:56	48	11:20	51	11:44	42		
10:57	46	11:21	52	11:45	41		
10:58	42	11:22	53	11:46	45		
10:59	42	11:23	51	11:47	48		

No.	I.H.P. Steam. Low Side.	High Side.	Total I.H.P. Steam.	I.H.P. Air Low Press.	High Press.	Total I.H.P. Air.	Mech. Eff. %
1.	11.38	10.77	21.15	10.50	9.44	19.94	94.2
2.	11.22	10.62	21.84	10.24	9.50	19.74	90.3
3.	12.08	11.38	23.46	11.29	10.29	21.58	92.0
4.	8.80	8.23	17.03	8.22	7.36	15.58	91.4
5.	8.82	8.32	17.14	8.01	7.23	15.24	88.9
6.	10.94	10.42	21.36	10.29	9.24	19.53	91.4
7.	9.70	9.11	18.81	8.27	5.68	13.95	74.1
8.	9.59	9.01	18.60	9.11	7.55	16.66	89.2
9.	9.80	9.27	19.07	9.08	7.77	16.85	88.3
10.	9.42	9.00	18.42	8.64	7.71	16.35	88.7
11.	11.27	10.67	21.94	10.07	9.46	19.53	89.0
12.	10.32	9.65	19.97	10.42	8.76	19.18	96.0
13.	10.06	10.89	20.95	8.98	8.35	17.33	82.7
14.	8.91	8.48	17.39	7.79	7.38	15.17	87.2
15.	10.34	9.73	20.07	9.46	8.74	18.20	90.6
16.	10.72	11.28	22.00	10.91	9.25	20.16	91.6
17.	8.90	8.45	17.23	8.35	7.23	15.58	89.8
18.	9.89	9.44	19.33	9.27	8.35	17.62	90.0
19.	8.88	8.22	17.10	8.14	7.26	15.40	90.0
20.	11.27	10.67	21.94	10.37	8.98	19.35	88.2
21.	13.75	13.19	26.94	12.59	11.19	23.78	89.0
22.	9.83	9.27	19.10	8.84	8.05	16.89	88.4
23.	12.77	12.08	24.85	11.82	10.36	22.18	89.2
24.	10.78	10.20	20.98	10.64	8.96	19.60	93.4

No.	I. H. P. Steam. Low Side.	High Side.	Total I. H. P. Steam.	I. H. P. Air. Low Press.	High Press.	Total I. H. P. Air.	Mech. Eff. %
25.	8.99	8.44	17.43	7.96	7.55	15.51	88.9
26.	13.03	12.55	25.57	11.25	11.01	22.26	87.0
27.	12.13	11.25	23.38	10.25	10.19	20.24	87.4
28.	8.73	9.04	18.77	8.48	8.29	16.77	89.3
29.	10.37	9.84	20.21	8.37	8.68	18.05	89.3
30.	11.71	10.81	22.52	10.22	10.08	20.30	94.6
31.	9.53	8.99	18.52	8.44	8.25	16.69	90.1
32.	10.07	9.64	19.71	8.57	8.40	16.97	84.1
33.	11.56	10.82	11.38	11.24	10.05	21.29	95.1
34.	8.74	8.05	16.79	7.72	7.15	14.87	88.5
35.	11.95	11.01	22.96	10.50	9.93	20.43	88.9
36.	10.75	9.93	20.68	9.78	9.17	18.95	91.6
37.	10.41	10.09	20.50	9.17	9.19	18.36	89.5

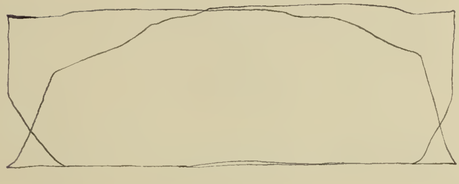
10-2-00-2M-O

UNIVERSITY OF ILLINOIS
MECHANICAL ENGINEERING LABORATORY

~~BOILER~~ PRES. 72
R. P. M. 45
SCALE 50
Area = 3.34 □"
M.E.P. = 50.60
I.H.P. = 4.0[illegible]

CARD NO. 17
END
CYLINDER 10X10
Area = 3.15 □"
M.E.P. = 47.72
I.H.P. = 4.02

Crosby 2-inch Drum



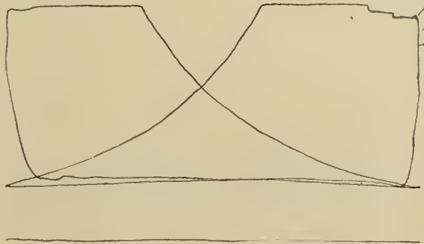
1-15-00-1M-O

UNIVERSITY OF ILLINOIS
MECHANICAL ENGINEERING LABORATORY

Air
~~BOILER~~ PRES. 115
R. P. M. 45
SCALE 60
Area = [illegible].0
M.E.P. 39.[illegible]
I.H.P. = [illegible].49

CARD NO. 17
END
CYLINDER 10X10
Area = 2.21"
M.E.P. = [illegible].38
I.H.P. = [illegible].74

Thompson $1\frac{1}{2}$-inch Drum



10-2-00-2M-O

UNIVERSITY OF ILLINOIS

MECHANICAL ENGINEERING LABORATORY

BOILER PRES. 72

R. P. M. 45

SCALE 50

Area = 3.43

M.E.P. 51.71

I.H.P. 4.47

CARD NO. 17

END

CYLINDER 10 X 16

Area = 3.43

M.E.P. 51.71

I.H.P. 4.45

Crosby 2-inch Drum

10-2-00-2M-O

UNIVERSITY OF ILLINOIS

MECHANICAL ENGINEERING LABORATORY

Air

BOILER PRES. 27

R. P. M. 45

SCALE 30

Area = 1.89

M.E.P 17.98

I.H.P. 4.08

CARD NO. 17

END

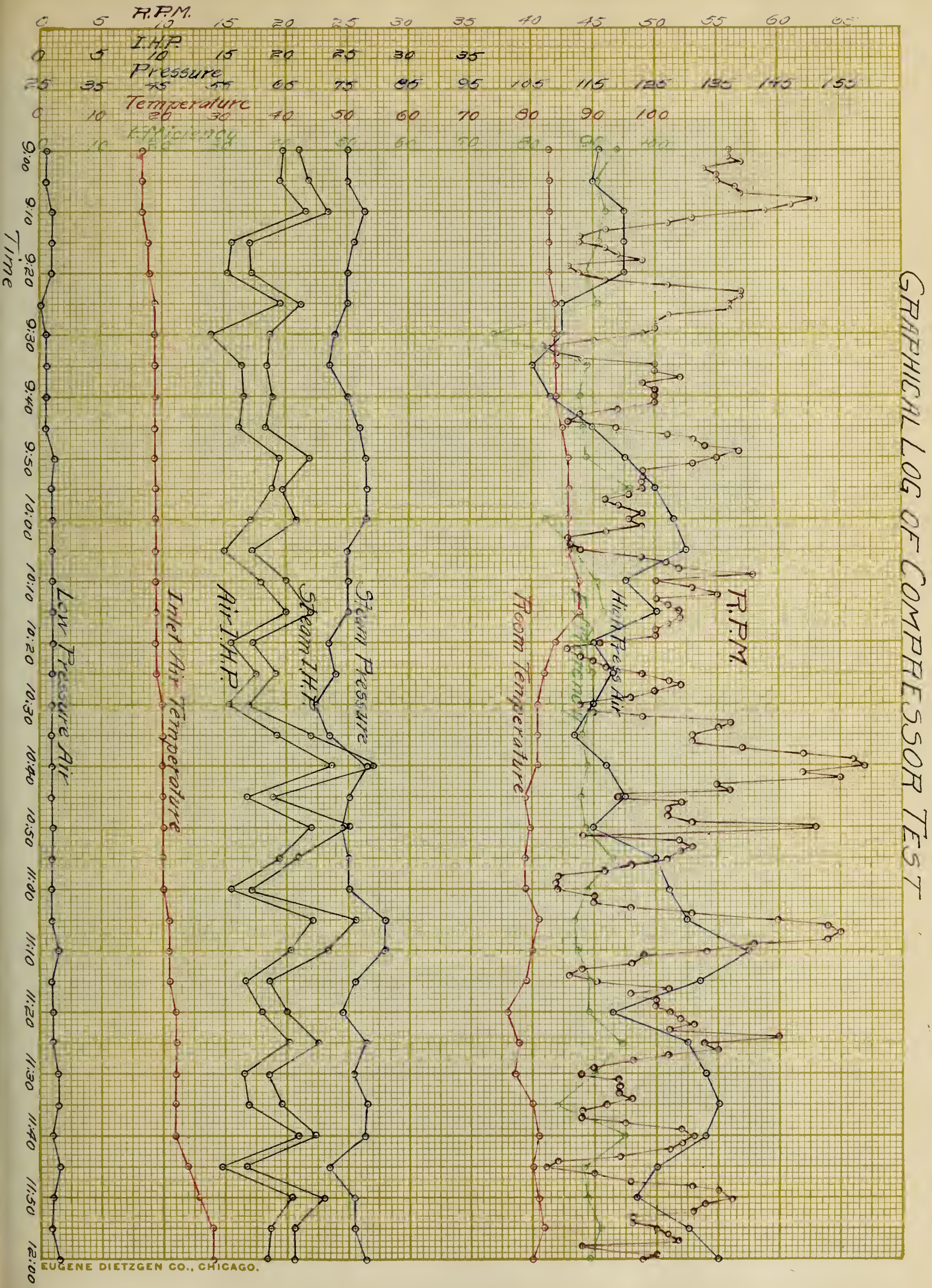
CYLINDER 10 X 16

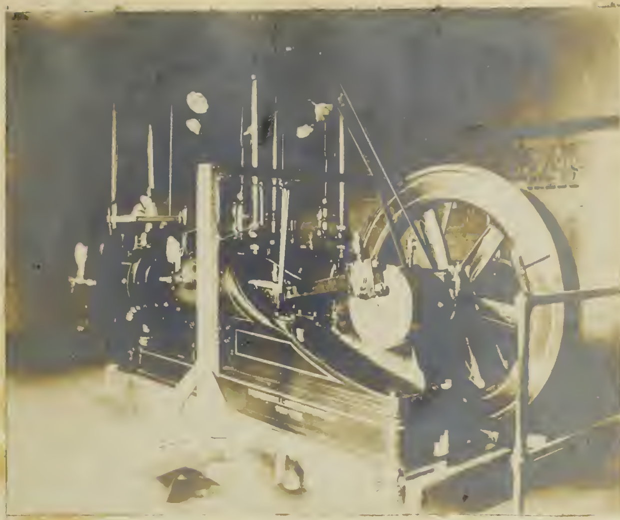
Area = 2.0 □"

M.E.P. = 19.92

I.H.P. = 4.27

Crosby 2-inch Drum


GRAPHICAL LOG OF COMPRESSOR TEST
R.P.M.
I.H.P.
Pressure
Temperature
Efficiency
Time
Low Pressure Air
Inlet Air Temperature
Air I.H.P.
Steam I.H.P.
Steam Pressure
Room Temperature
High Press Air
R.P.M.
EUGENE DIETZGEN CO., CHICAGO.



Test of a Compound Marine Steam Engine Run by Compressed Air.

The object of the test was to determine the amount of air consumed per. brake-horse-power-hour using air at different pressures and running the engine at different speeds. Also to find the value of heating the air.

The engine used was the 2 3/8" x 4 1/4" x 3 1/8" Marine Engine in the Mechanical Engineering Laboratory at the University of Ill.

To accomplish this object, tests of one hour duration were run at constant pressure and brake load; the revolutions of the engine and brake load were recorded, also the amount of air used during the test, which was found by keeping track of the compressor, by continuous counter and multiplying the number of revolutions of compressor during the test by the weight of air compressed per stroke, the pressure inthe tank being brought to the same point as at the beginning of the test.

The amount of air compressed per revolution of compressor was found as follows: The receiver was carefully calibrated as to volume by filling it with water at the top of the tank until full and then let run out at the bottom and carefully weighed. This being repeated several times to insure accuracy.

The volume of the pipe from the compressor to tank and from the tank to engine was calculated and added to the calibrated volume of the tank. The total volume was found to be 90.447 cubic feet.

Thermometers were inserted in the side of the tank to get the temperature near the top and bottom and the average was used. The

continuous counter was placed on the compressor to get the total number of revolutions.

The tank being empty the compressor was started and the number of revolutions required to pump the air in the tank from 0 pounds to 100 pounds noted also the average temperature of the air in the tank at 0 pounds and 100 pounds.

From this the weight of free air pumped in was calculated by means of the formula $G-G' = V/R\ (p/T-p'/T')$ in which G = weight of air, p = absolute pressure and T= absolute temperature at 100 pounds gauge pressure and G',p',T', denote the same at 0 pounds gauge pressure. $G-G'$ = weight of air pumped into the tank which divided by the total number of revolutions of the compressor equals the amount of free air in pounds compressed per. revolution.

To find the brake horse-power of the engine multiply the perimeter of the circle having the length of the brake arm,which is 2 1/6 feet by the number of revolutions of the engine and by the weight on scale less weight of brake arm and divide this product by 33000.

Dividing the horse power of the engine by the weight of air used per. hour we have the air consumption in pounds per. brake-horse-power-hour. To find the cubic feet at 60 degrees F. multiply the number of pounds by 12.61.

To find the result of reheating compare the results of tests with the same initial pressure at engine and same number of revolutions of the engine.

To get pressure and temperature before entering the engine a pressure gauge and thermometer were inserted between the throttle

valve and the engine. A thermometer was also inserted in the pipe between *the* high and low pressure cylinders to get *the* temperature of the air, also one in the exhaust pipe.

Tests were run at 50, 65 and 80 pounds initial pressure, regulated by a hand governed throttle valve, with engine running at 200, 300 and 400 R.P.M. each. The temperature of air was noted in each test before entering, between cylinders and in the exhaust pipe.

Tests were run using cold air, air heated before entering engine and before entering and between cylinders.

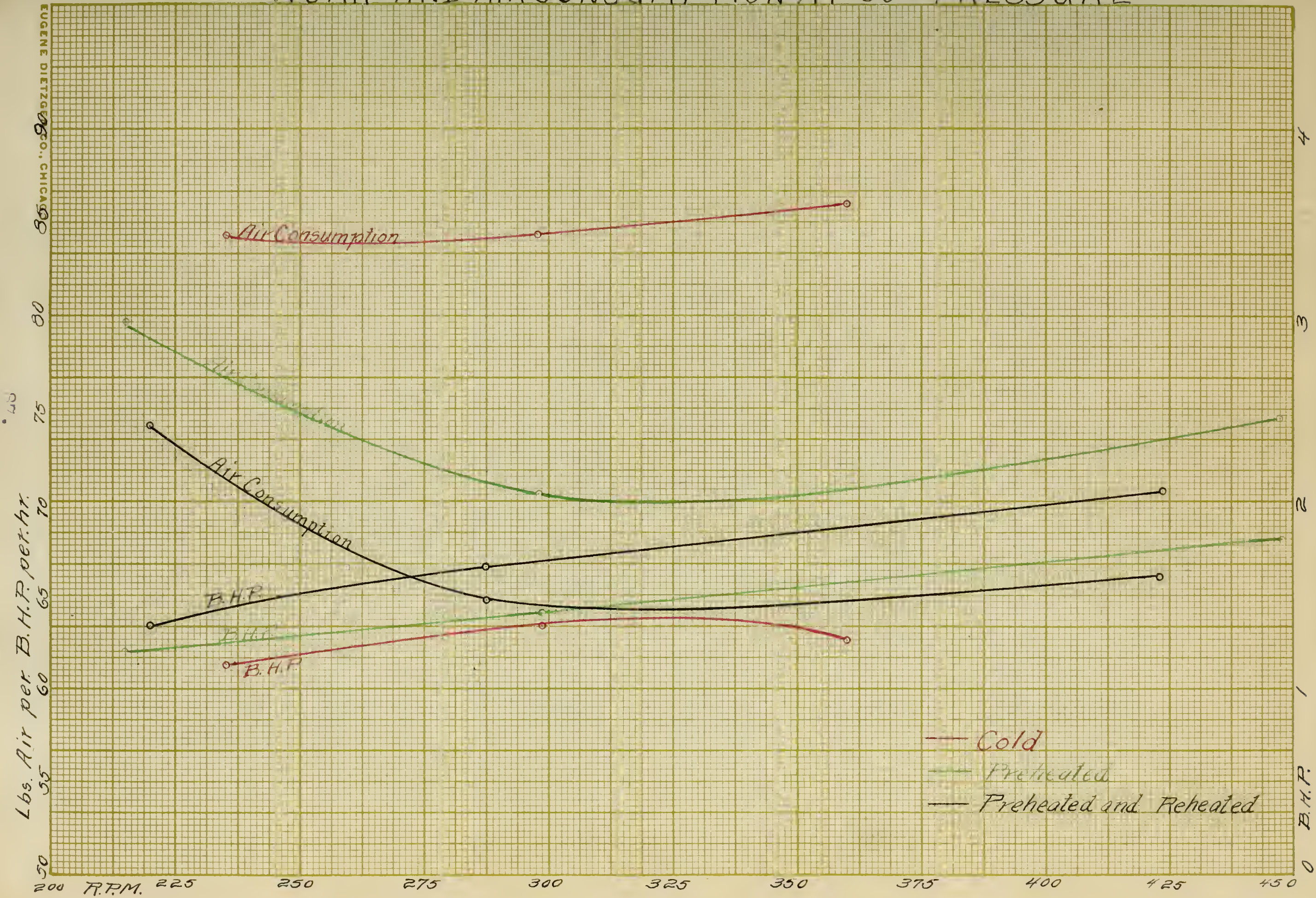
The air was heated between cylinders by means of a gas flam under a long pipe which was inserted in place of the short connection originally there.

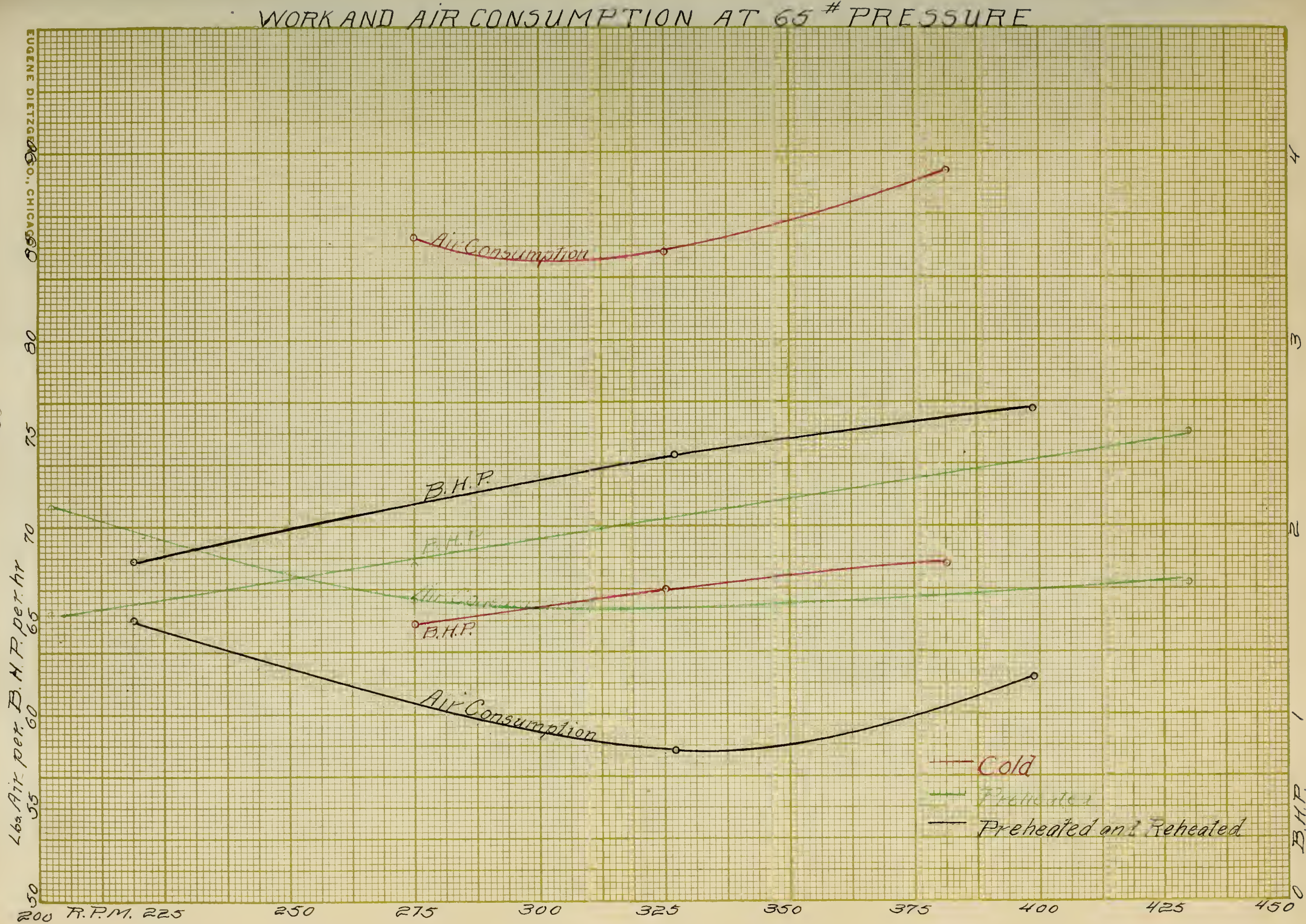
The following sheets contain tabulated results and value of reheating, also photographs to show arrangement of brake and reheating connections.

No.	Time. hrs.	R.P.M.	Press.	Load.	Temperatures Before entering.	Between cylinders.	Exhaust.	B.H.P.	Total air used.	Air per. B.H.P. per. hour. Lbs.	Cu. Ft.
1.	1	360	50	9	81		30	1.28	110.62	85.6	1079.4
2.	1	297	50	11	82		25	1.34	112.92	84.2	1065.7
3.	1	234	50	12	81		30	1.15	97.06	84.4	1064.2
4.	1	381	65	11.5	82		12	1.80	160.0	88.8	1119.7
5.	1	325	65	13	82		10	1.69	142.6	84.3	1062.9
6.	1	272	65	14	82		12	1.48	126.6	85.5	1078.1
7.	1	372	80	16	82		0	2.32	199.0	85.8	1081.9
8.	1	344	80	18	82		0	2.55	198.77	77.8	981.0
9.	1	284	80	19.5	82		-2	2.28	183.38	80.4	1013.8
10.	1	446	50	10	205		57	1.83	135.03	74.5	939.4
11.	1	296	50	12	230		62	1.43	103.91	70.3	886.4
12.	1	216	50	13.3	230		54	1.18	94.25	79.8	1006.2
13.	1	434	65	14	200		30	2.51	168.43	67.1	846.1
14.	1	275	65	17	215		45	1.81	119.91	56.1	833.5
15.	1	203	65	18.8	210		45	1.57	111.47	71.0	895.3
16.	1	398.	80	18	173		40	2.95	191.75	65.0	819.6
17.	1	307	80	21.3	190		30	2.69	175.4	64.0	807.0
18.	1	238	80	23	200		30	2.28	157.8	69.1	871.3
19.	1	421	50	12	175	255	110	2.08	137.98	66.0	832.2
20.	1	288	50	14	215	255	115	1.66	107.38	64.6	814.6
21.	1	217	50	15	212	250	105	1.34	99.94	74.0	933.1
22.	1	398	65	16	175	208	75	2.62	162.44	62.0	781.8
23.	1	329	65	17.5	197	247	95	2.38	138.04	58.0	731.3
24.	1	219	65	20	220	250	105	1.80	117.04	65.0	819.6

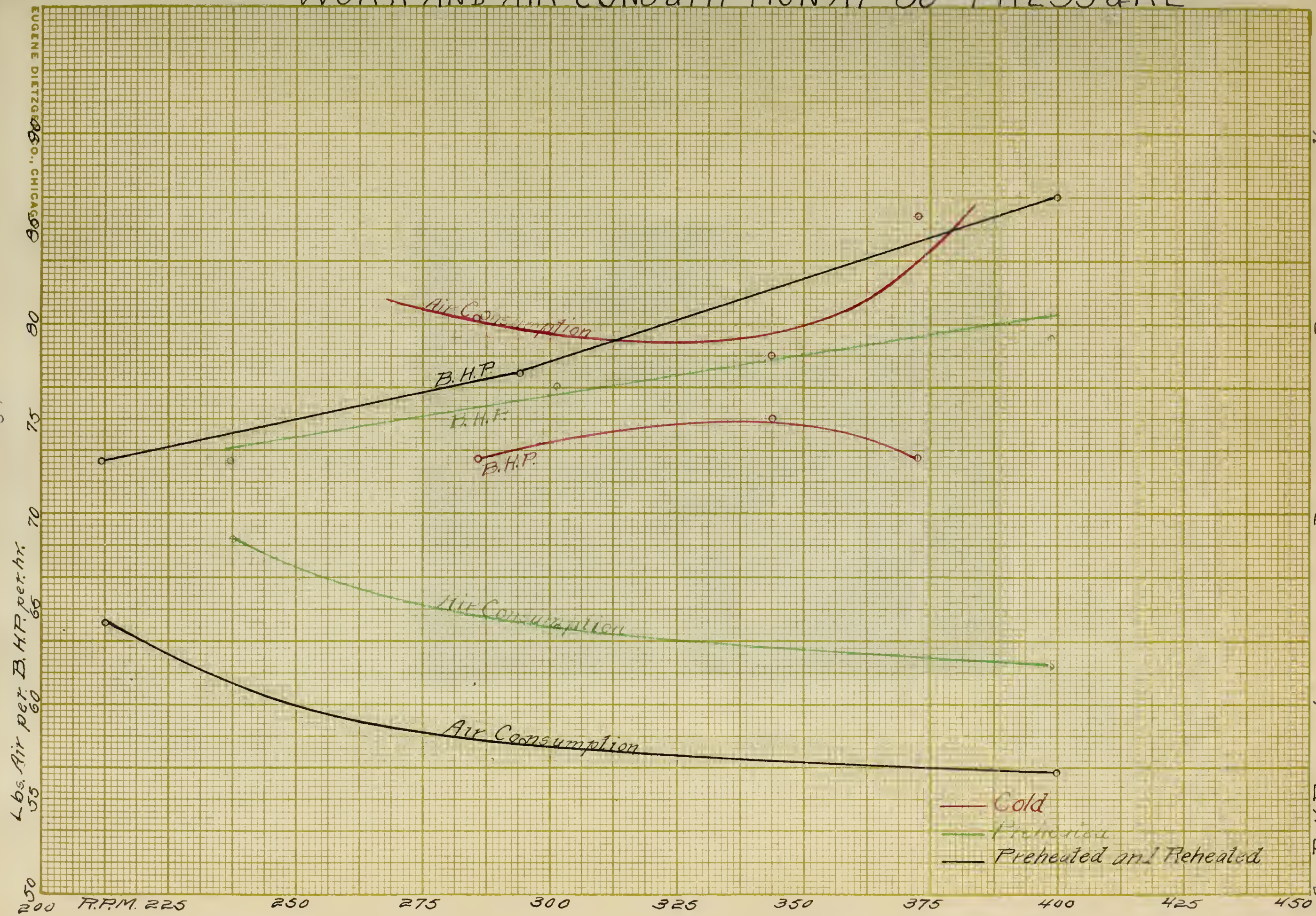
No.	Time. hrs.	R.P.M.	Press.	Load.	Temperatures. Before entering.	Between cylinders.	Exhaust.	B.H.P.	Total. air used.	Air per. B.H.P. per. hour. lbs.	cu.ft.
25.	1	400	80	20.5	165	190	65	3.68	207.2	56.5	712.4
26.	1	295	80	23	177	217	70	2.76	165.6	58.0	731.3
27.	1	211	80	26	188	245	87	2.26	145.2	64.2	809.5

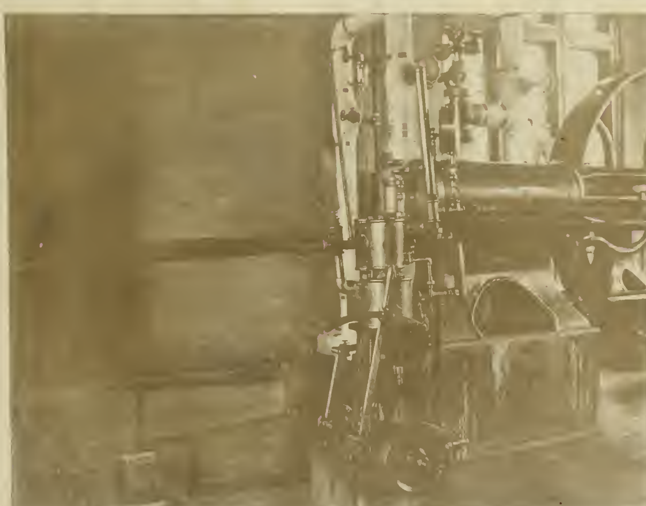
WORK AND AIR CONSUMPTION AT 50# PRESSURE




WORK AND AIR CONSUMPTION AT 65 # PRESSURE
Air Consumption
B.H.P.
B.H.P.
B.H.P.
Air Consumption
Lbs. Air per. B.H.P. per hr
R.P.M.
B.H.P.
Cold
Preheated and Reheated
EUGENE DIETZGEN CO., CHICAGO

WORK AND AIR CONSUMPTION AT 80# PRESSURE





Tests on an Oscillating Steam Engine Run by Compressed Air.

The object of the test was to find the amount of air consumed per. brake horse power per. hour using air at different pressures and running the engine with different brake loads from zero to a maximum. Also to find the value of heating the air.

The engine used in these tests was the oscillating engine used to run the Babcock and Wilcox chain grate at the University of Illinois heating and boiler plant.

The engine was removed from its foundation, taken into the testing laboratory and connected up with air as shown in the accompaning photograph.

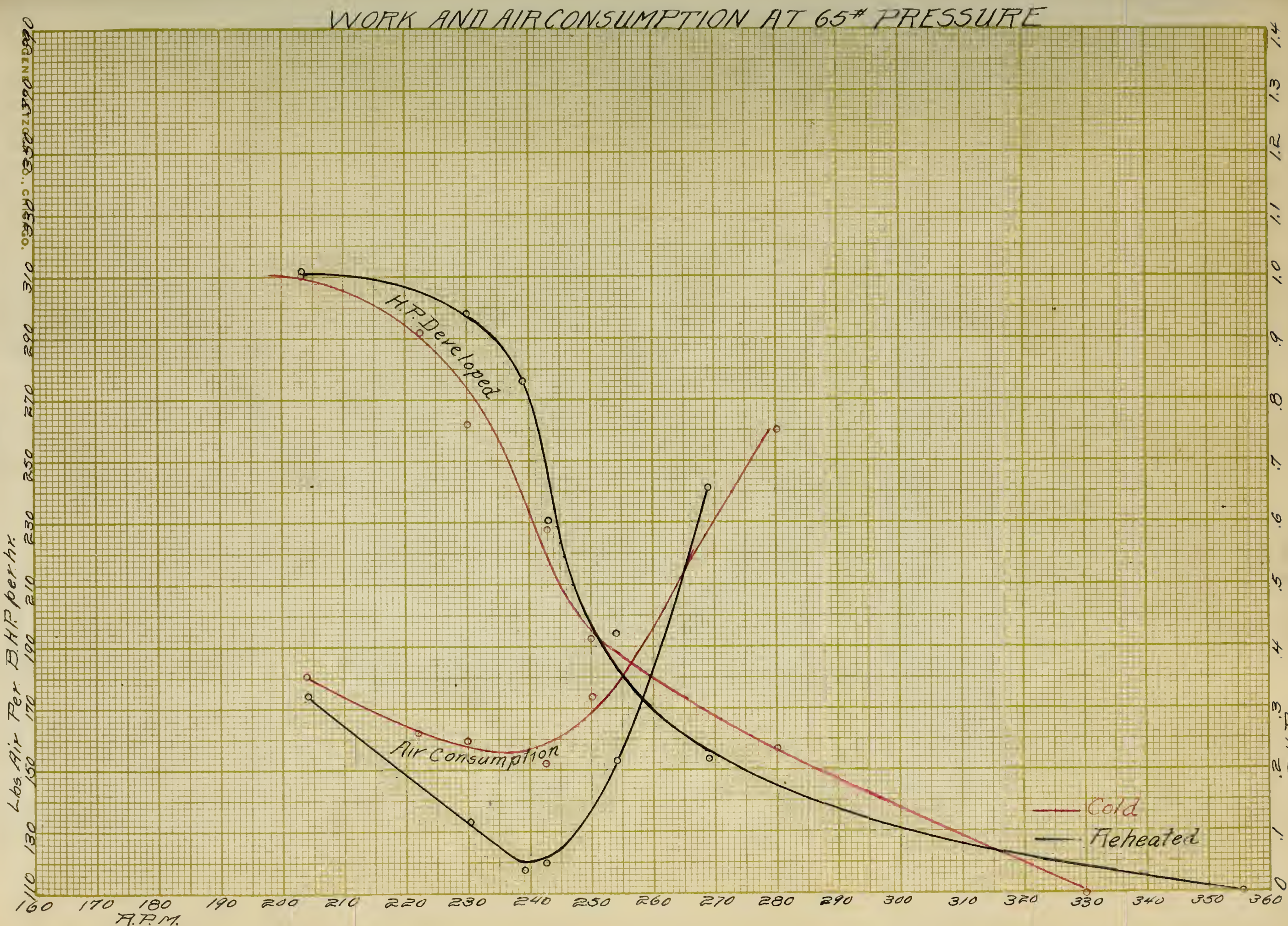
Owing to the limits of time tests of fifteen minutes duration were run with air at 65 pounds and 80 pounds pressures and brake loads of 0, 2, 4, 6, 8, 10, 12, and 14 pounds using air cold; then the tests were repeated using air heated.

The air consumption was obtained in the same way as in the previous test.

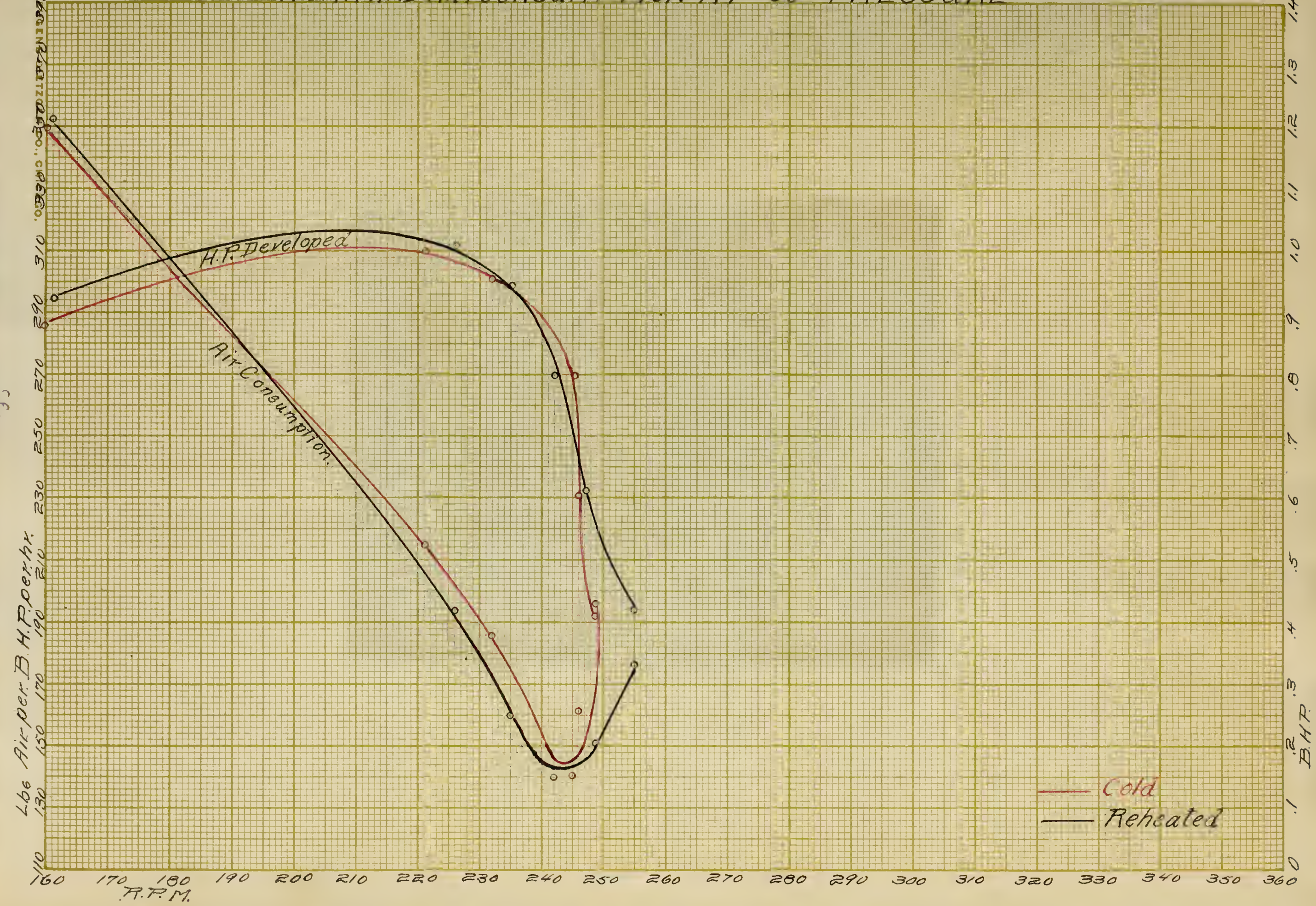
The following pages show the data and results of the tests.

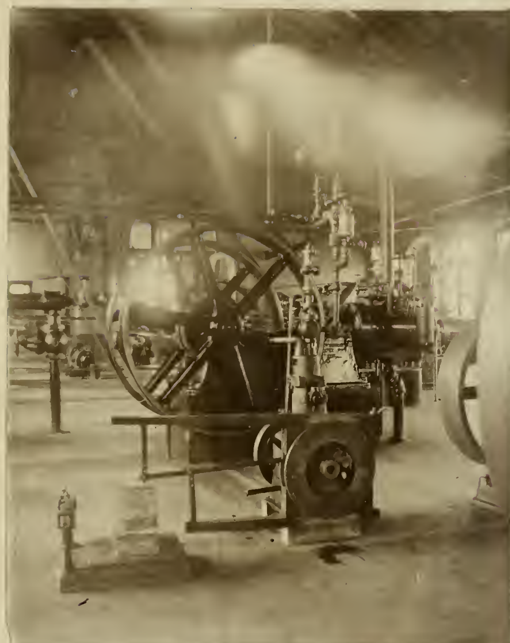
No.	Time. mins.	R. P. M.	Press.	Load.	Temperatures. Before.	Exhaust.	B. H. P.	Total. air used.	Air per. B. H. P. hr. Lbs.	Cu. Ft.
1.	15	330	65	0	89	72	.0	14.96		
2.	15	280	65	2	89	62	.23	15.02	260.	3276
3.	15	250	65	4	90	55	.41	18.20	172.8	2177
4.	15	243	65	6	90	50	.59	22.79	152.4	1920
5.	15	230	65	8	89	42	.75	31.33	160.8	2026
6.	15	222	65	10	90	38	.91	36.91	161.2	2031
7.	15	204	65	12	91	40	1.00	45.42	180.0	2268
8.	15	249	80	4	96	40	.41	20.05	195.2	2459
9.	15	246	80	6	96	34	.60	24.55	161.2	2031
10.	15	245	80	8	90	25	.80	28.46	140.8	1774
11.	15	232	80	10	90	27	.95	44.50	186.4	2348
12.	15	221	80	12	91	32	1.09	58.92	215.2	2711
13.	15	157	80	14	96	45	.89	77.50	348.4	4389
14.	15	365	65	0	200	94	.0	13.03		
15.	15	269	65	2	200	93	.22	13.34	241.2	3039
16.	15	254	65	4	200	88	.42	16.00	153.6	1934
17.	15	242	65	6	200	76	.59	17.89	119.6	1506
18.	15	239	65	8	200	74	.83	24.51	118.0	1486
19.	15	230	55	10	190	72	.94	31.94	134.6	1695
20.	15	203	65	12	165	70	1.00	44.00	175.2	2207
21.	15	255	80	4	200	97	.42	18.53	176.4	2222
22.	15	247	80	6	200	86	.61	23.03	150.4	1895
23.	15	242	80	8	200	76	.80	28.29	140.0	1764
24.	15	235	80	10	195	78	.96	38.93	160.4	2021

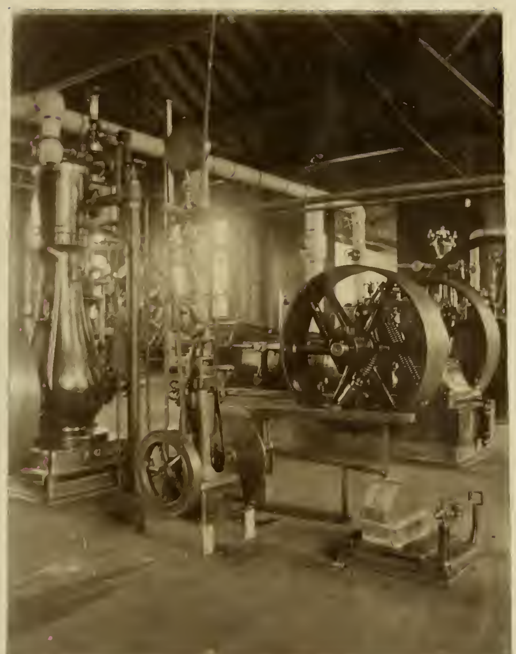
No.	Time. mins.	R.P.M.	Press.	Load.	Temperature. Before.	Exhaust.	B.H.P.	Total air used.	Air per. B.H.P. hr. Lbs.	Cu. Ft.
25.	15	226	80	12	175	79	1.12	54.06	182.8	2429
26.	15	161	80	14	158	90	.92	81.95	352.8	4435


WORK AND AIR CONSUMPTION AT 65# PRESSURE
H.P. Developed
Air Consumption
Cold
Reheated
Lbs. Air Per B.H.P. per hr.
B.H.P.
R.P.M.
160 170 180 190 200 210 220 230 240 250 260 270 280 290 300 310 320 330 340 350 360
110 130 150 170 190 210 230 250 270 290 310
0 .1 .2 .3 .4 .5 .6 .7 .8 .9 1.0 1.1 1.2 1.3 1.4

WORK AND AIR CONSUMPTION AT 80# PRESSURE







Comparison of Actual and Theoretical Gain in Heating Air.

Let I = Indicated Horse Power using air cold.

I' = " " " " " heated.

B = Brake " " " " cold.

B' = " " " " " heated.

T = Temperature of air cold.

T' = " " " heated.

v = Volume of air cold.

v' = " " same weight of air heated.

$I = pv \times$ some constant.

$I' = pv' \times$ " "

But with constant pressure $v : v' = T : T'$, therefore $I : I' = T : T'$, with constant weight of air.

$$I' = I \times T'/T.$$

$$B = I - F.$$

$$B' = I' - F = I \times T'/T - F.$$

$$B' - B = I\,(T'/T - 1) = I\,\frac{(T' - T)}{T}$$

$$\text{Gain and B.H.P.} = \frac{B' - B}{B} = \frac{I}{B}\,\left(\frac{T' - T}{T}\right).$$

$$\text{Gain in I.H.P.} = \frac{T' - T}{T}.$$

Evidently from the equations the gain in B.H.P. is greater than the gain in I.H.P. in the ratio $I : B$; hence experiments in which B.H.P. only were used should show a greater gain per. cent from reheating than is given by the equations. This is the case in the experiments tried. The temperatures were 82 and 200 degrees F. so that $T = 543$, $T' = 661$. Therefore the gain in I.H.P. = .2175.

From actual case the gain in B.H.P. = .244.

If we assume the efficiency of the engine to be .80 then I / B = 1 /.80 = 1.25; hence $\frac{I}{B} \times \frac{(T' - T)}{T} = 1.25 \times .2173 = .2717$ which should be the gain in B.H.P.